

# CKY Parsing

LING 571 — Deep Processing Techniques for NLP

October 11, 2021

Shane Steinert-Threlkeld

# Announcements

- HW1 grades posted; will aim for Mondays in general
- Some notes:
  - Make sure dir structure of your submission is correct [generally, no nested directories]
  - Run `check_hwX.sh` before submitting!
  - Pay careful attention to format of output files; make sure there's exact match on toy examples
  - patas/dryas, etc: will regrade HW1 if that was an issue
  - **Use full paths for python binaries to be safe**

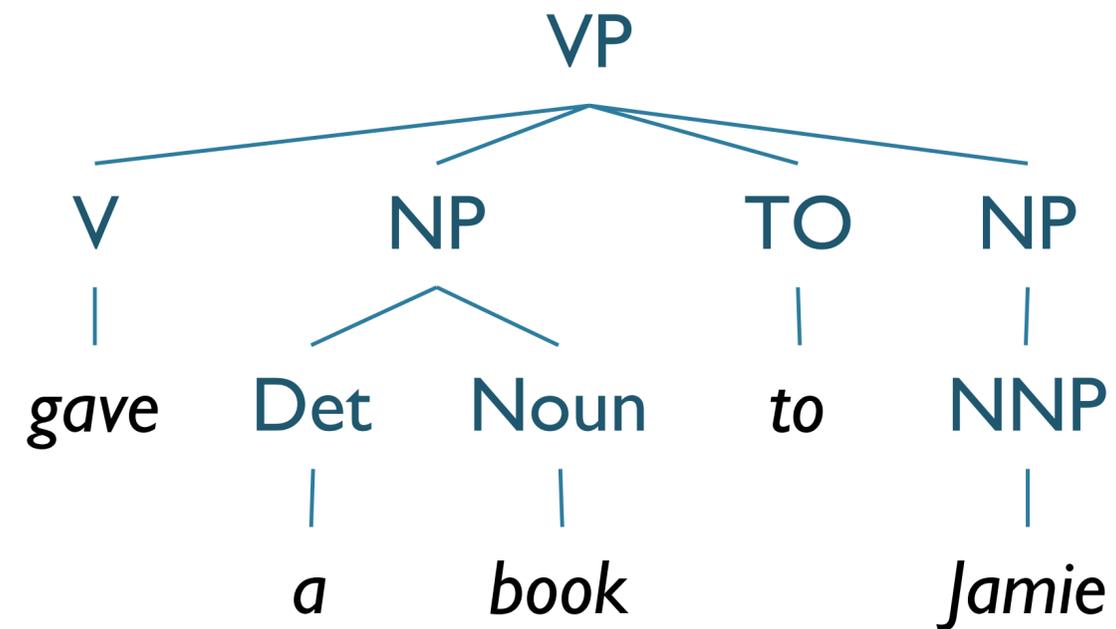
# Announcements: HW #2

- Due Wednesday, 11:59pm Pacific
- Grammar output format:
  - Terminals quoted (single or double)
  - One production per line
  - *Optionally*, RHS alternates with vertical bar/pipe character: |
  - Start symbol is first nonterminal encountered in file
- Execute the conversion rules in the order that they are on the slides.
- Unit productions: any *non-unit* RHS that can be reached by a sequence of units. I updated the CNF slides to be clearer on this.

# Variation in CNF: Binarization

Original Rule

$VP \rightarrow V NP TO NP$



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## Left to Right Reduction

$VP \rightarrow X1 TO NP$

$X1 \rightarrow V NP$

$VP \rightarrow X2 NP$

$X2 \rightarrow X1 TO$

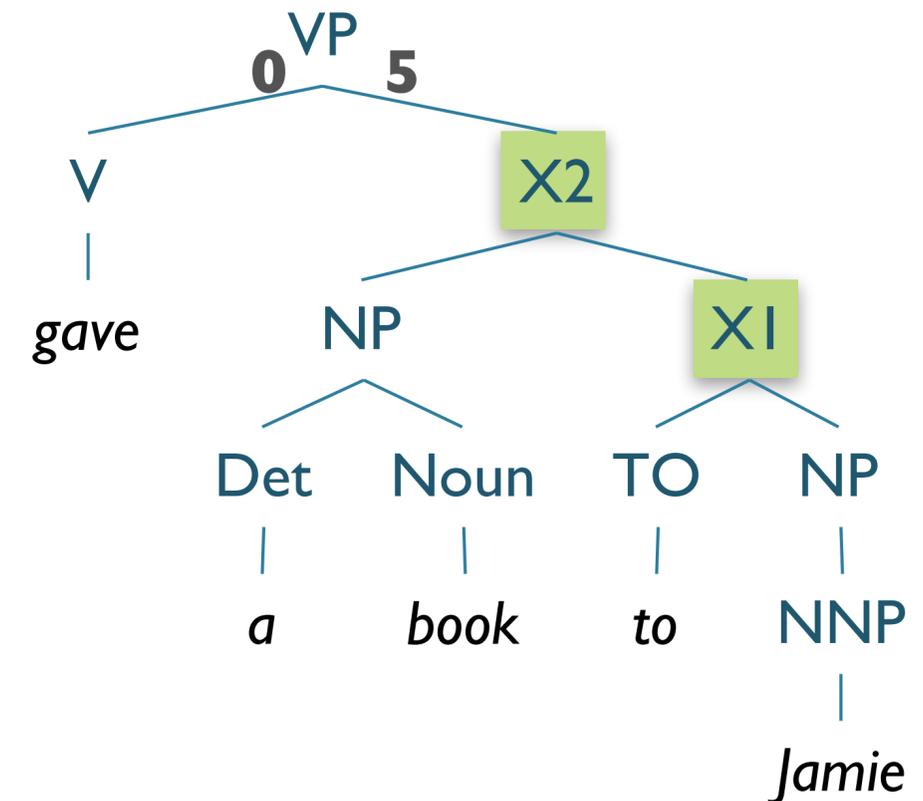
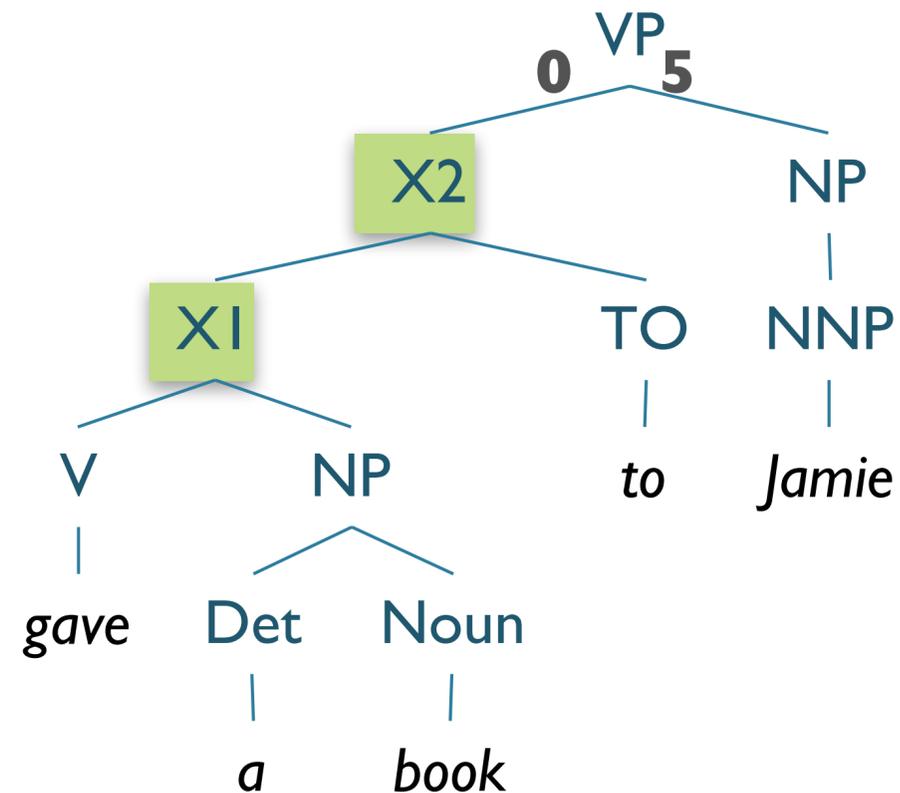
## Right to Left Reduction

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$X1 \rightarrow TO NP$

$VP \rightarrow V X2$

$X2 \rightarrow NP X1$



# Indigenous Peoples' Day

- Seattle/Sealth/Si'ahl



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  - siʔat̚ [ˈsiʔaːt̚]



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- IPA resources:
  - [https://en.wikipedia.org/wiki/International\\_Phonetic\\_Alphabet](https://en.wikipedia.org/wiki/International_Phonetic_Alphabet)
  - <http://web.mit.edu/6.mitx/www/24.900%20IPA/IPAapp.html>



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- Lushootseed exhibits debatable distinction between verbs and nouns [link to Glottolog page for more references]
  - **?uǰ<sup>w</sup> ti sbiaw**  
**goes that-which is-a-coyote**  
"The/a coyote goes"
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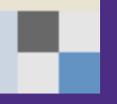
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*via Beck, 2013*
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"The one who goes is a coyote"
    - (Translation distinction provided for clarity — semantically equivalent)
- Lillooet Salish quantification has repercussions for e.g. English (Matthewson 2001)



**Can you name any other languages indigenous to the Americas?**



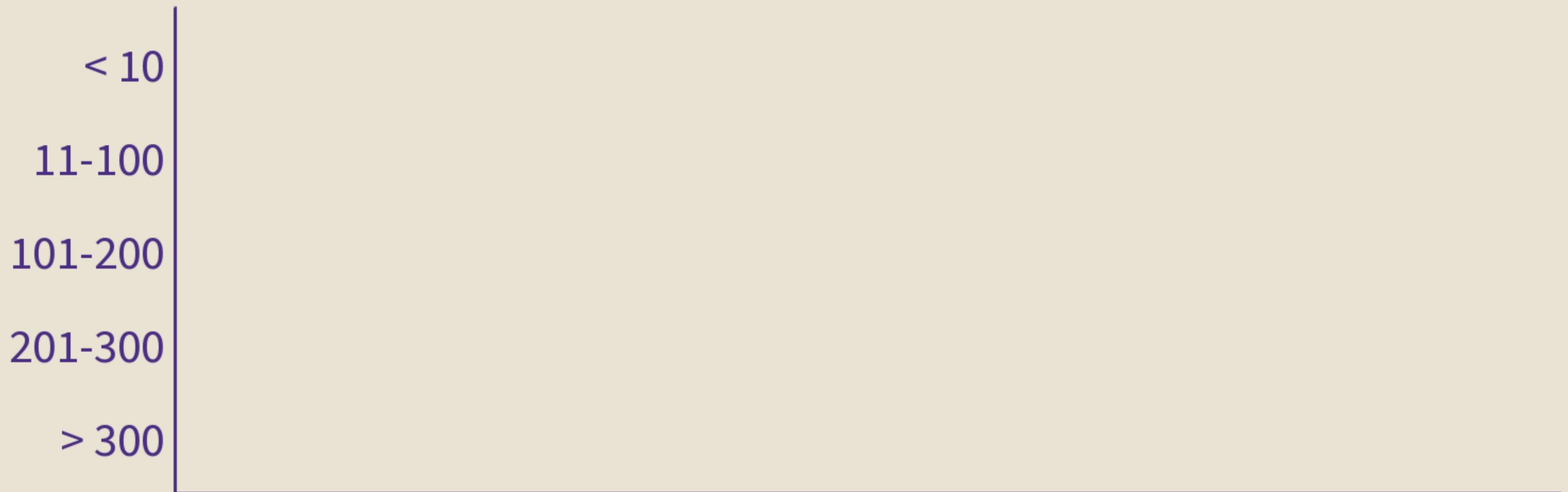
A large, empty, light beige rectangular area intended for user input or a poll.



🌐 When poll is active, respond at [pollev.com/shanest](https://pollev.com/shanest)

📱 Text **SHANEST** to **22333** once to join

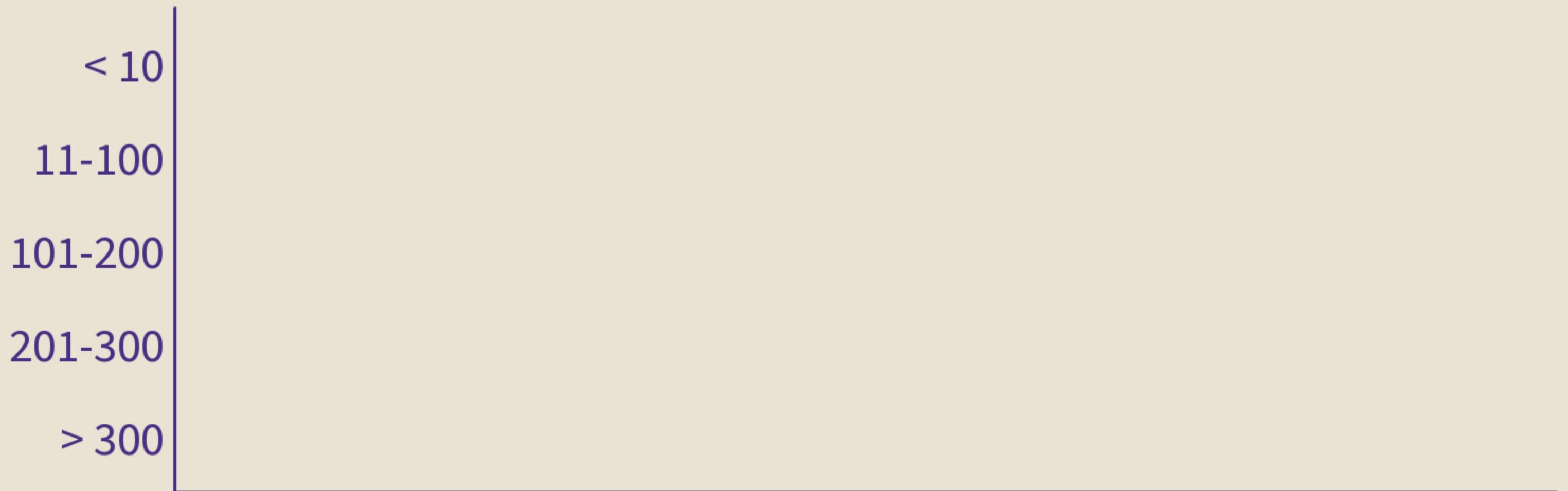
# W How many indigenous languages do you think there are in the US today?



🌐 When poll is active, respond at [pollev.com/shanest](https://pollev.com/shanest)

📧 Text **SHANEST** to **22333** once to join

# **W** How many languages do you think were spoken in the now-US at the time Europeans arrived?



# Indigenous Peoples' Day

- UW American Indian Studies Courses
  - (Sometimes including language courses, e.g. Southern Lushootseed)
- Lushootseed resources: <https://tulaliplushootseed.com/>

# Roadmap

- CKY Parsing Algorithm
  - Dynamic programming structure
  - Algorithm and example
  - Analysis & Discussion
  
- Next time: Probabilistic CFGs
  - Motivation: Ambiguity
  - Augmenting CFGs with probabilities

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  - $[ j - 1, j ]$  contains pre-terminals
  - if  $[ 0, n ]$  contains the start symbol, the sentence is ***accepted***

# CKY Matrix

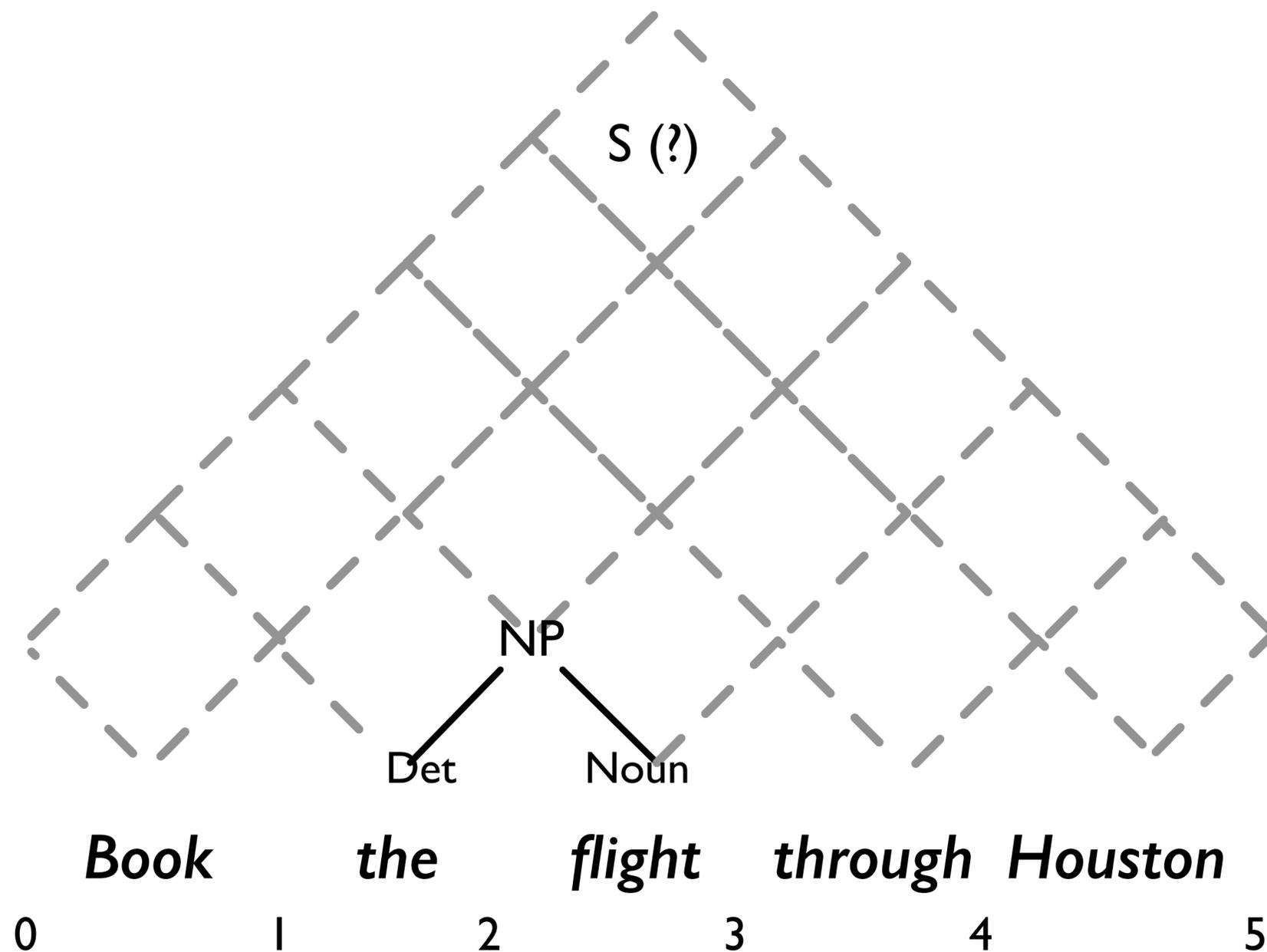
<i>Book</i>	<i>the</i>	<i>flight</i>	<i>through</i>	<i>Houston</i>
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	[1,2]	[1,3]	[1,4]	[1,5]
		[2,3]	[2,4]	[2,5]
			[3,4]	[3,5]
				[4,5]







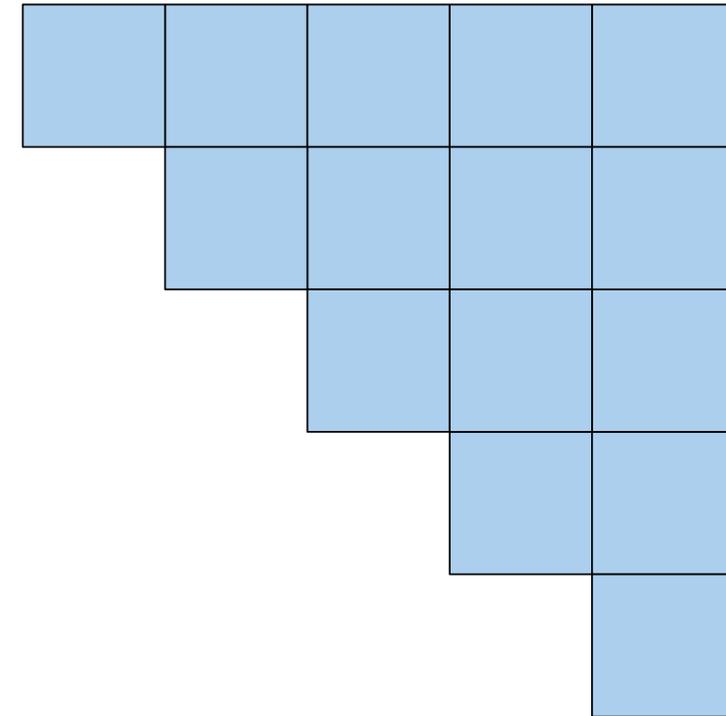
# CKY Matrix



# Dynamic Programming in CKY

- Key idea:
  - for  $i < k < j$
  - ...and a parse spanning substring  $[ i, j ]$
  - There is a  $k$  such that there are parses spanning  $[ i, k ]$  and  $[ k, j ]$
  - We can construct parses for whole sentences by building from these partial parses
- So to have a rule  $A \rightarrow B C$  in  $[ i, j ]$ 
  - Must have  $B$  in  $[ i, k ]$  and  $C$  in  $[ k, j ]$  for some  $i < k < j$
  - CNF forces this for all  $j > i + 1$

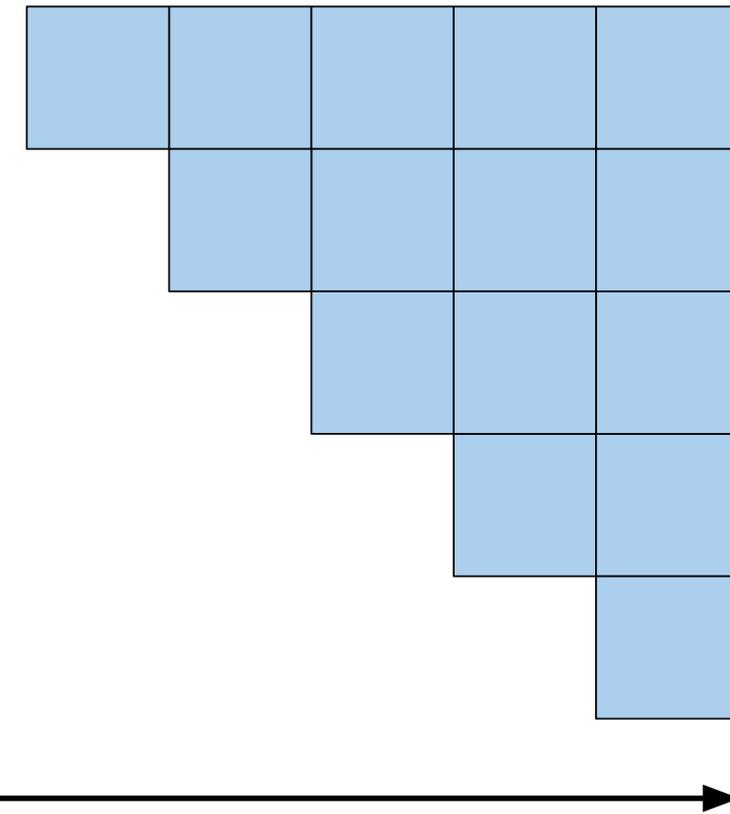
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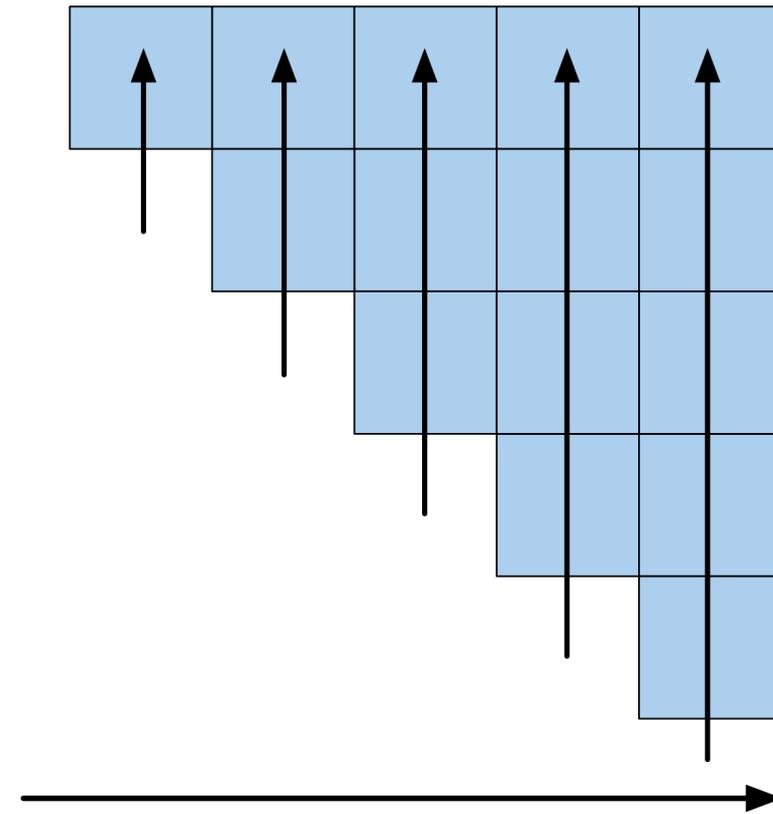
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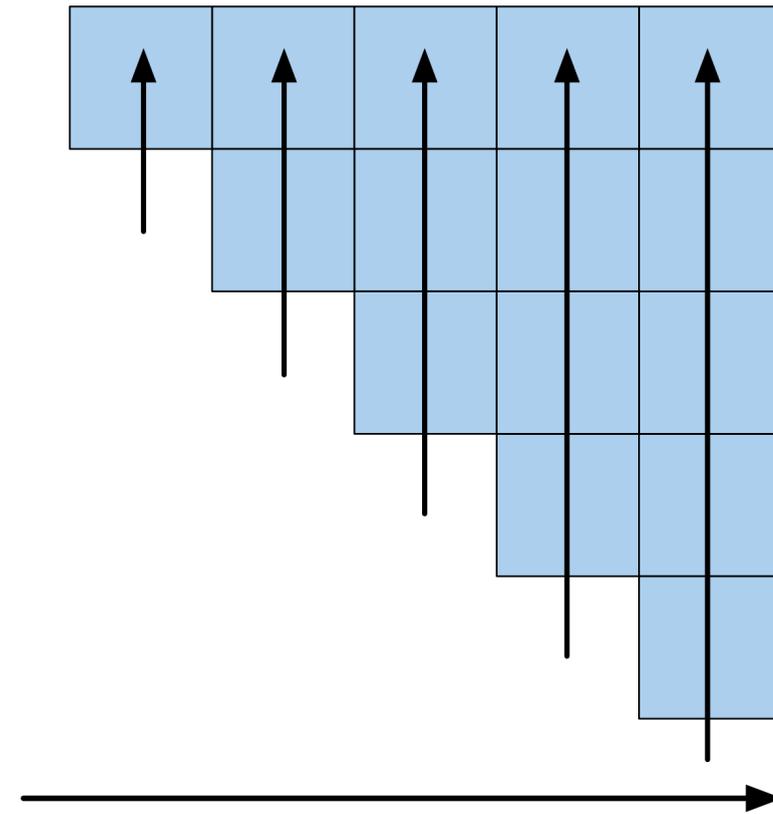
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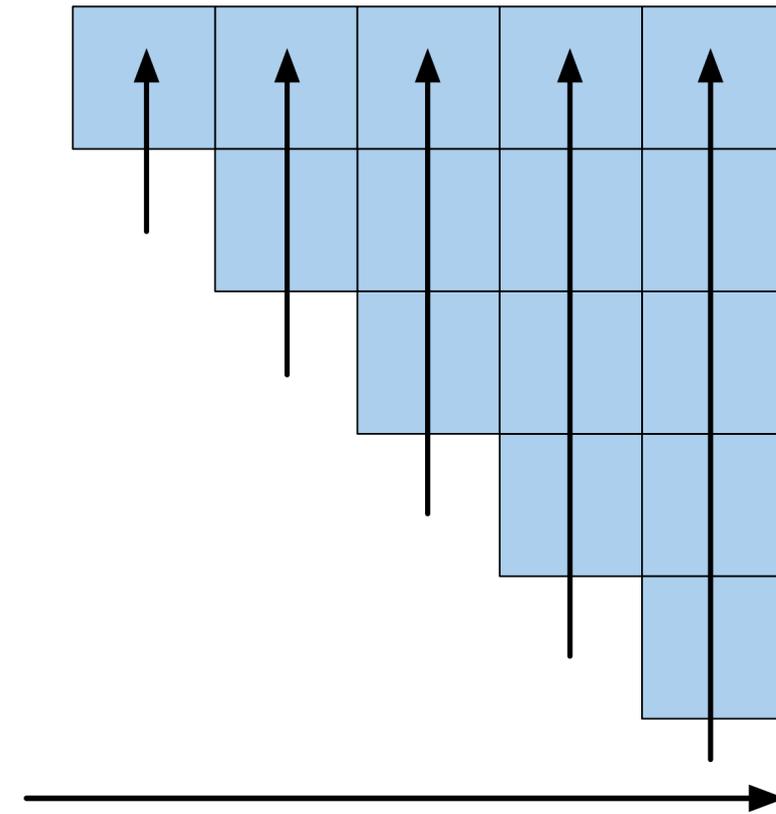
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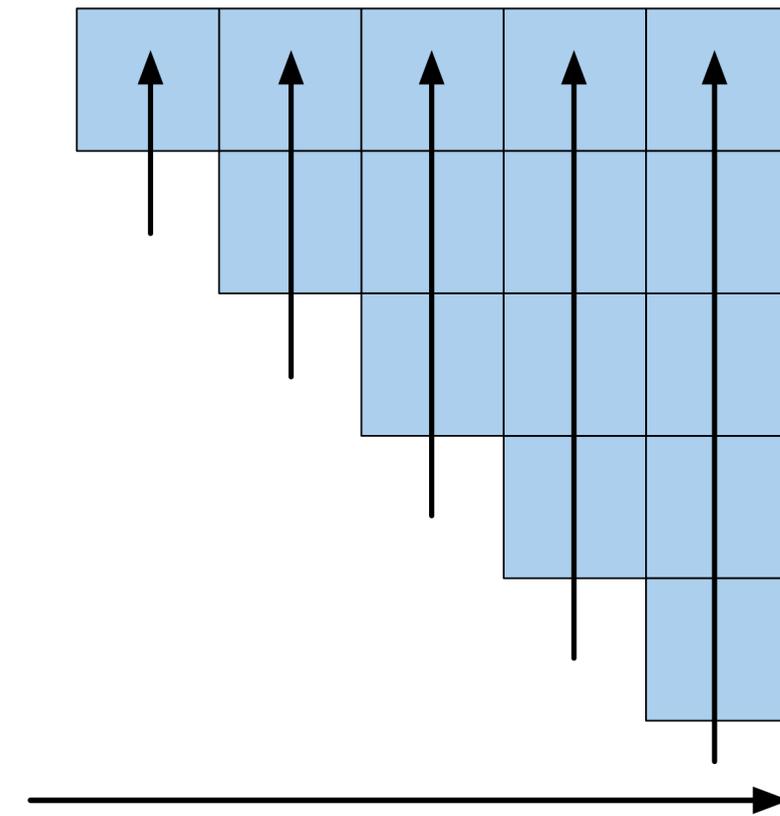


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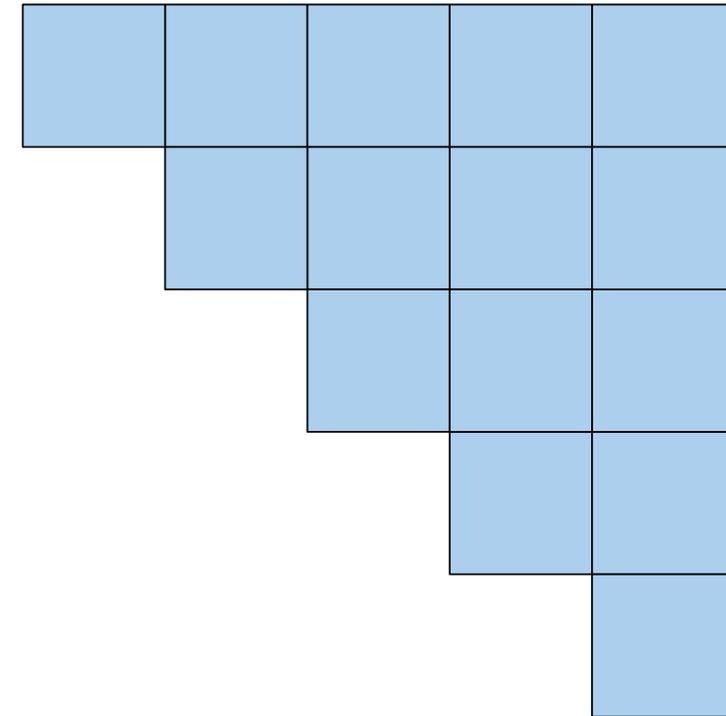


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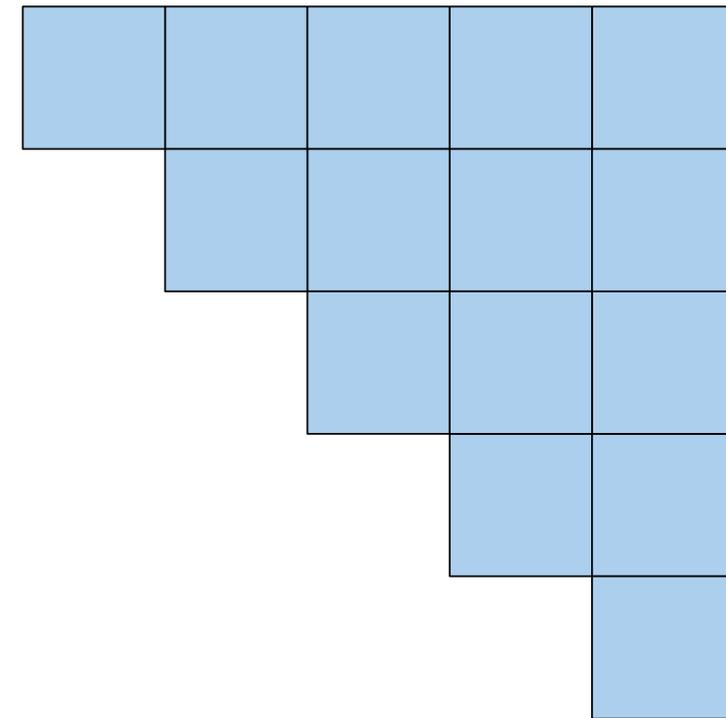
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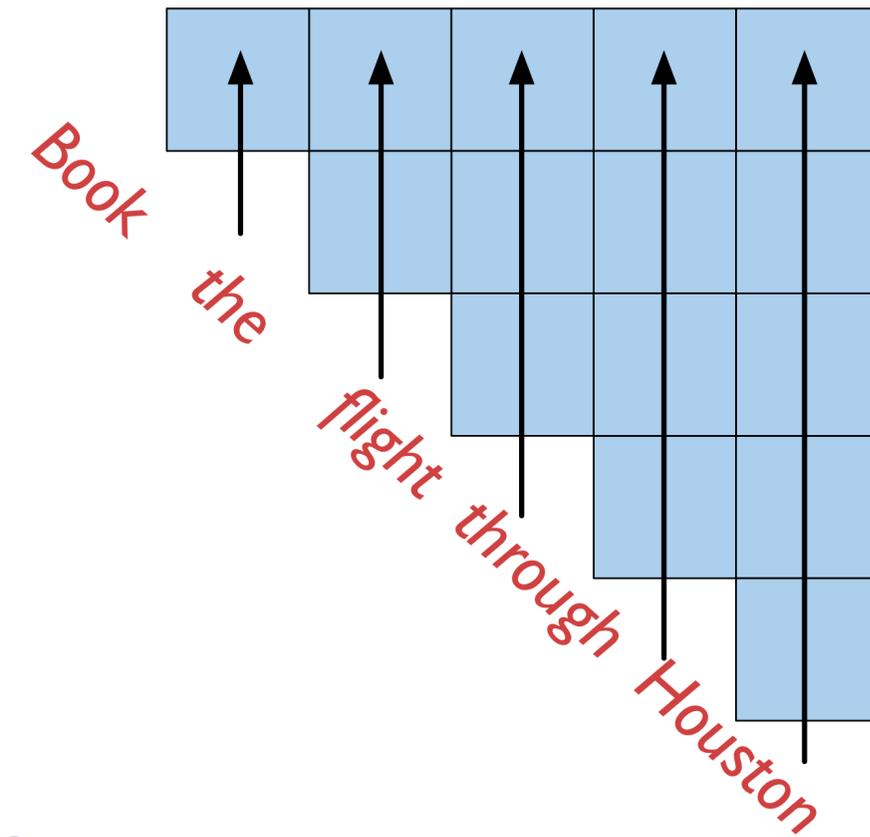
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  table[ j - 1, j ]  $\leftarrow$  { A | A  $\rightarrow$  words[ j ]  $\in$  grammar }
  for i  $\leftarrow$  from j - 2 downto 0 do
    for k  $\leftarrow$  i + 1 to j - 1 do
      table[ i, j ]  $\leftarrow$  table[ i, j ]  $\cup$ 
      { A | A  $\rightarrow$  BC  $\in$  grammar
        B  $\in$  table[ i, k ],
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Left-to-right, bottom-to-top

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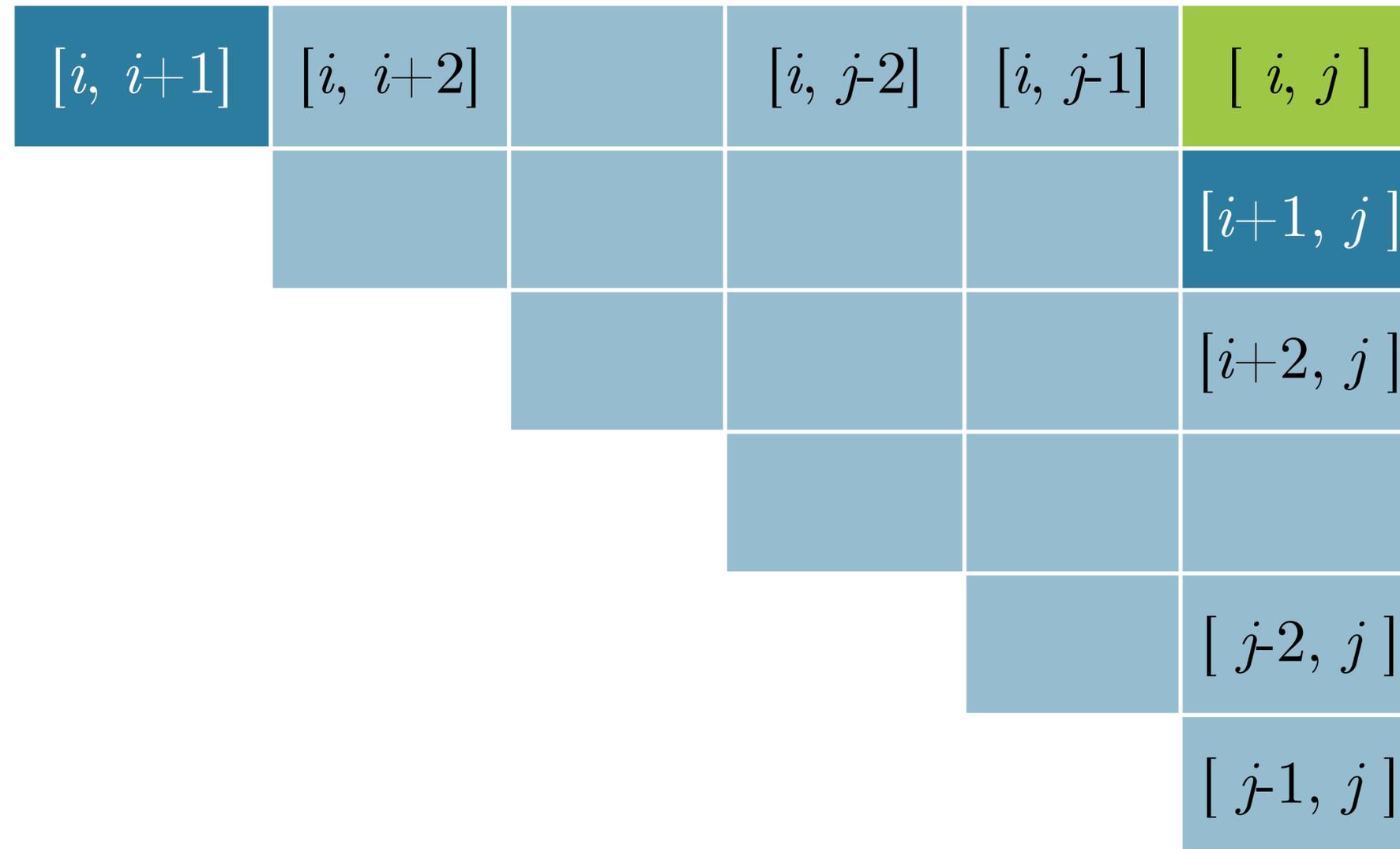
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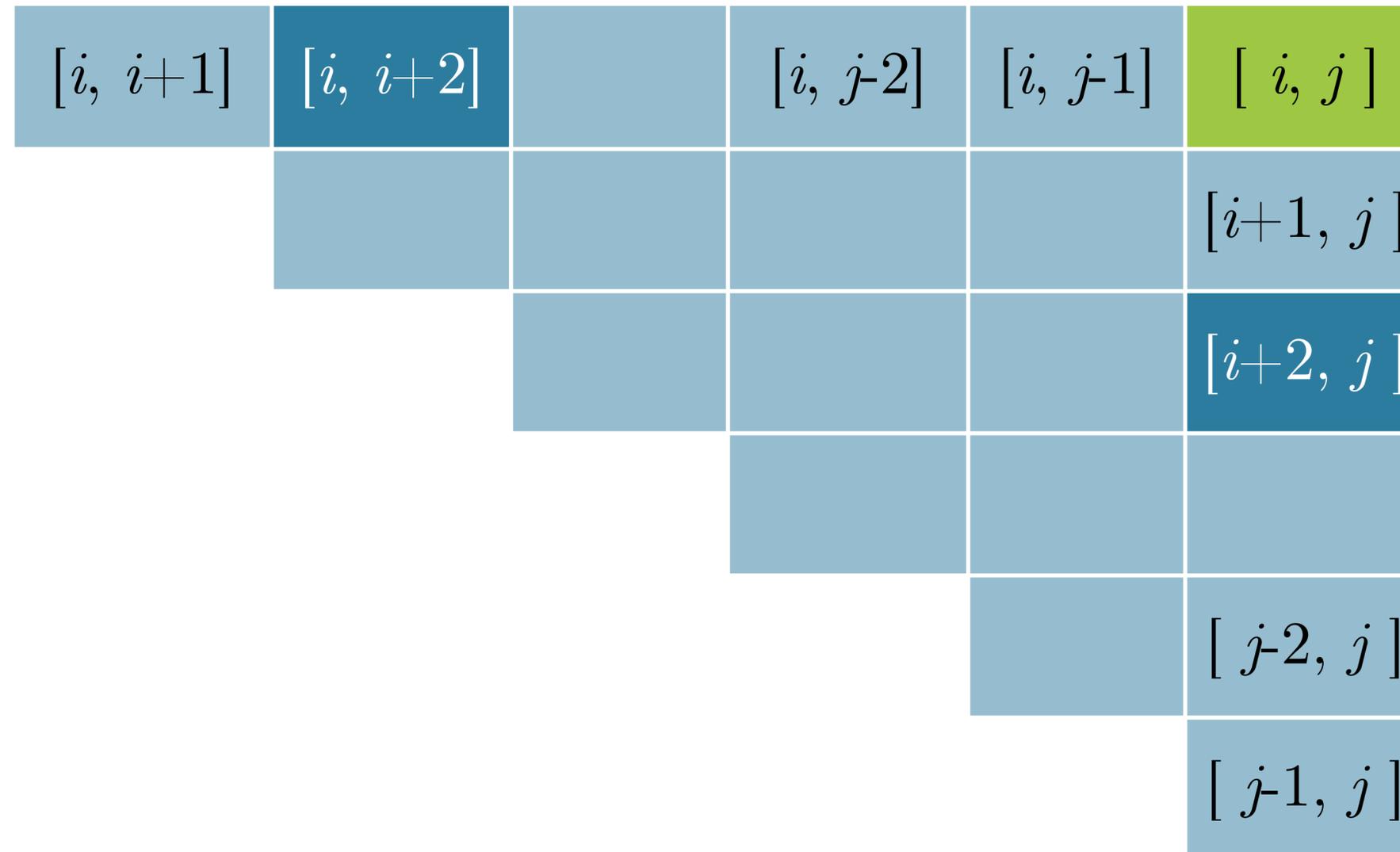
Filling the cell with set of applicable rules

# Filling Cell $[i, j]$



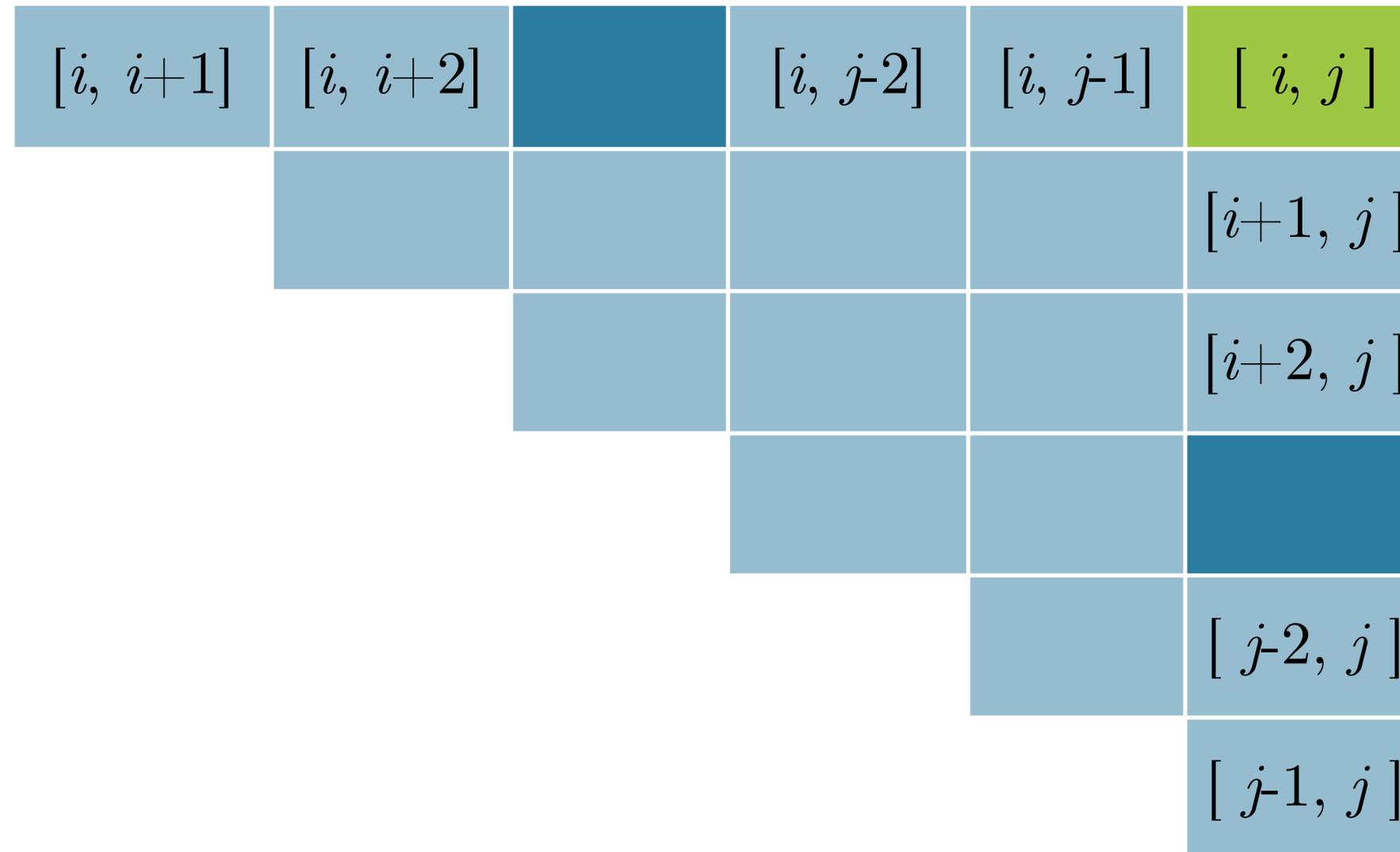
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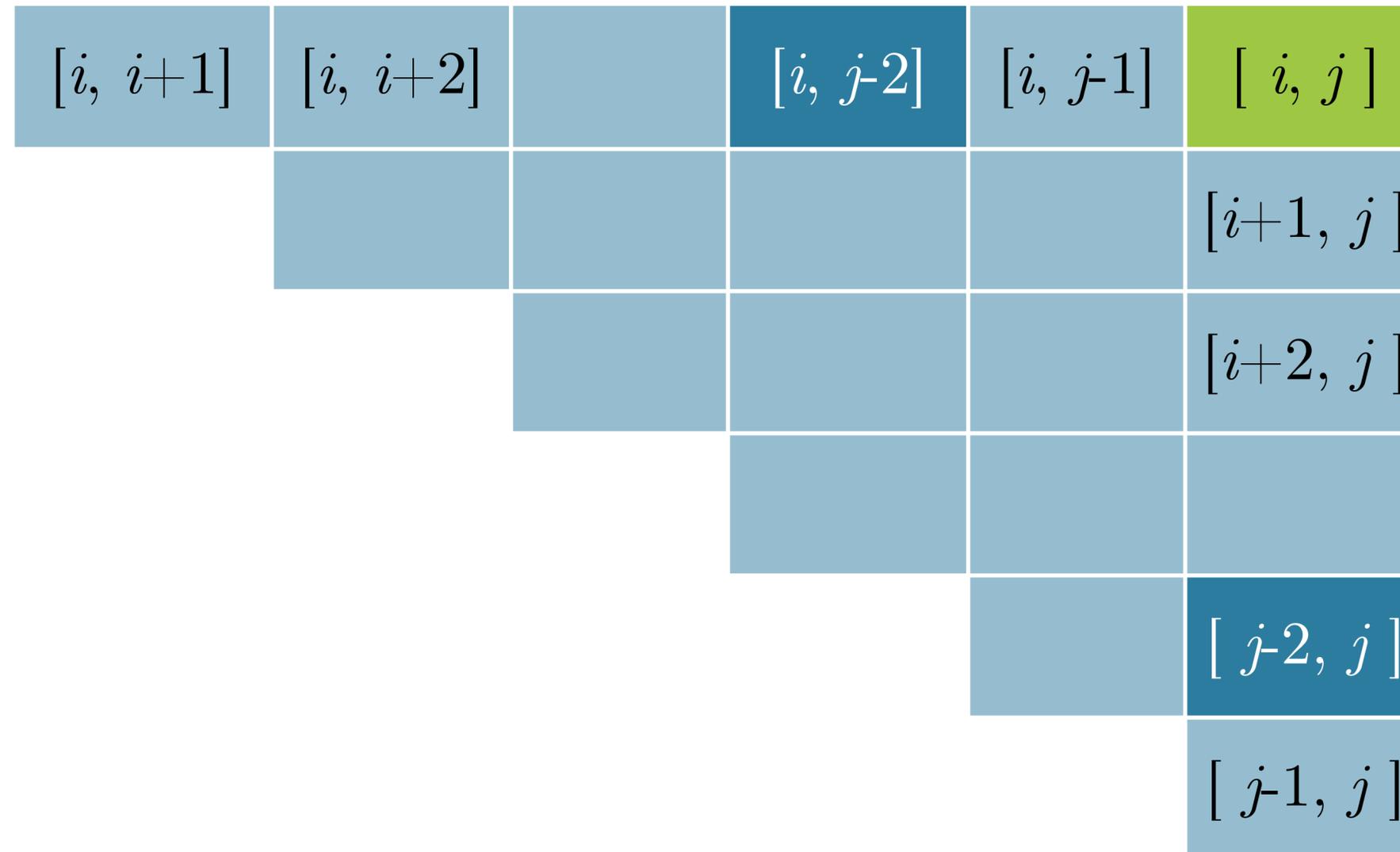
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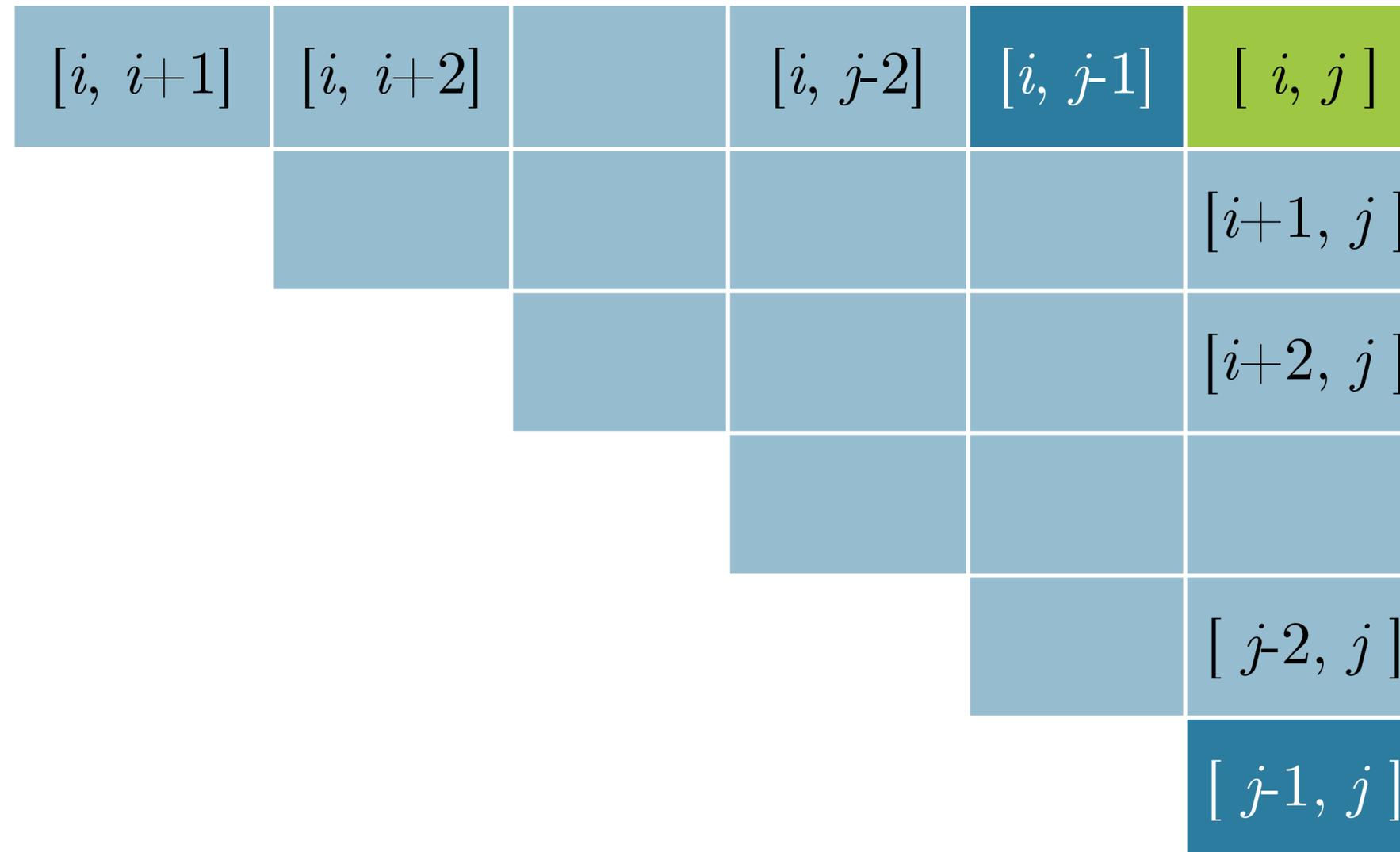
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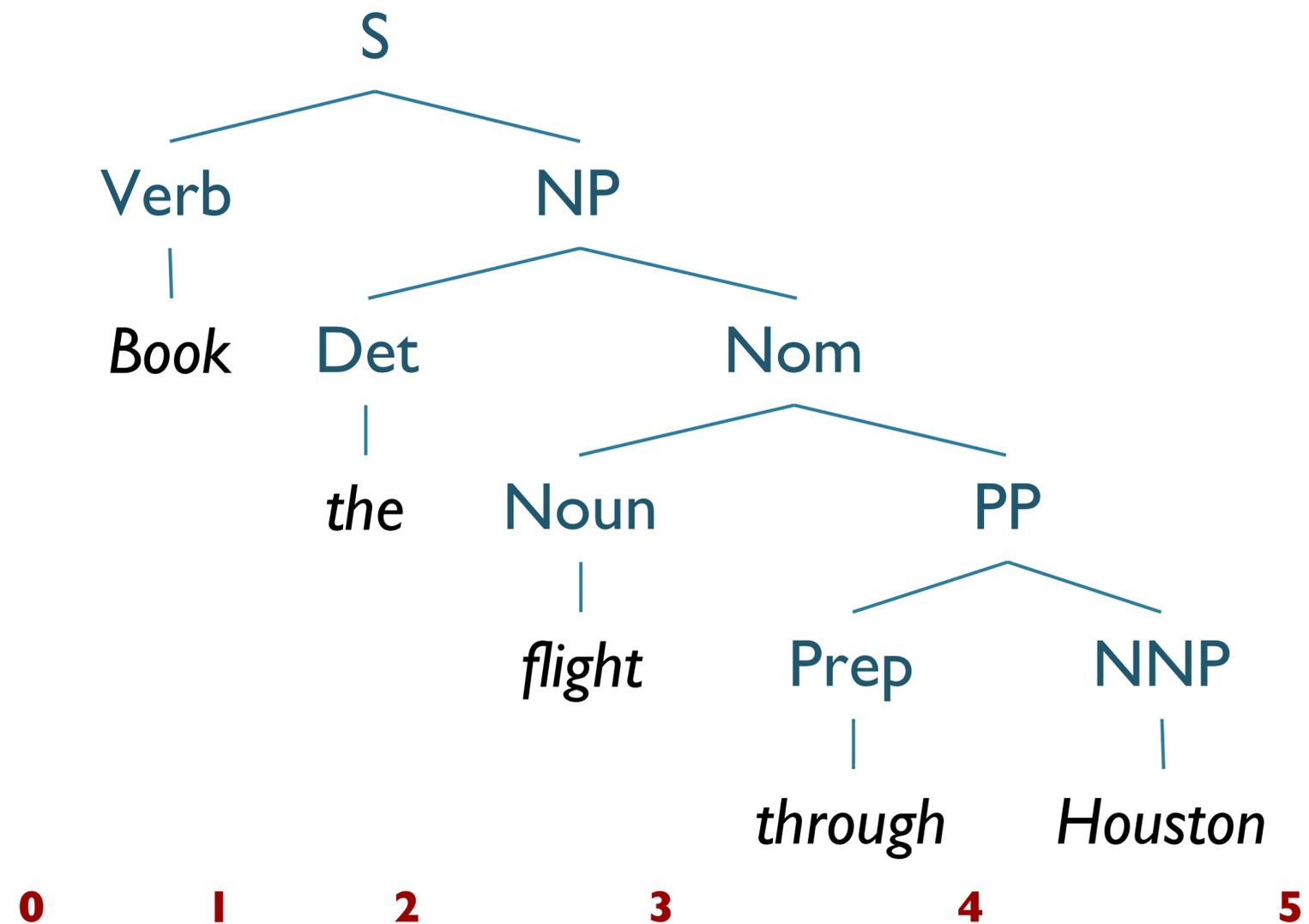
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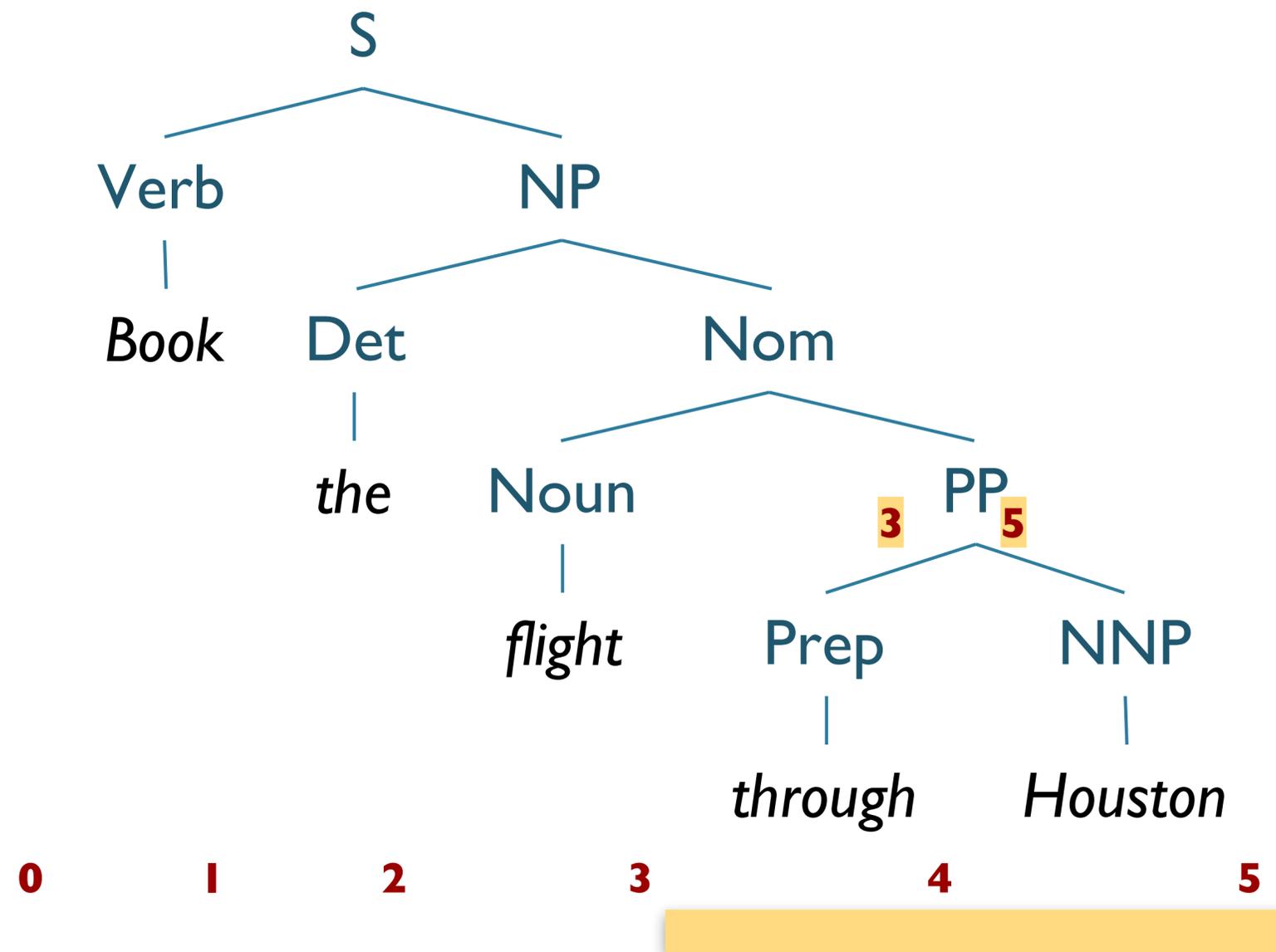
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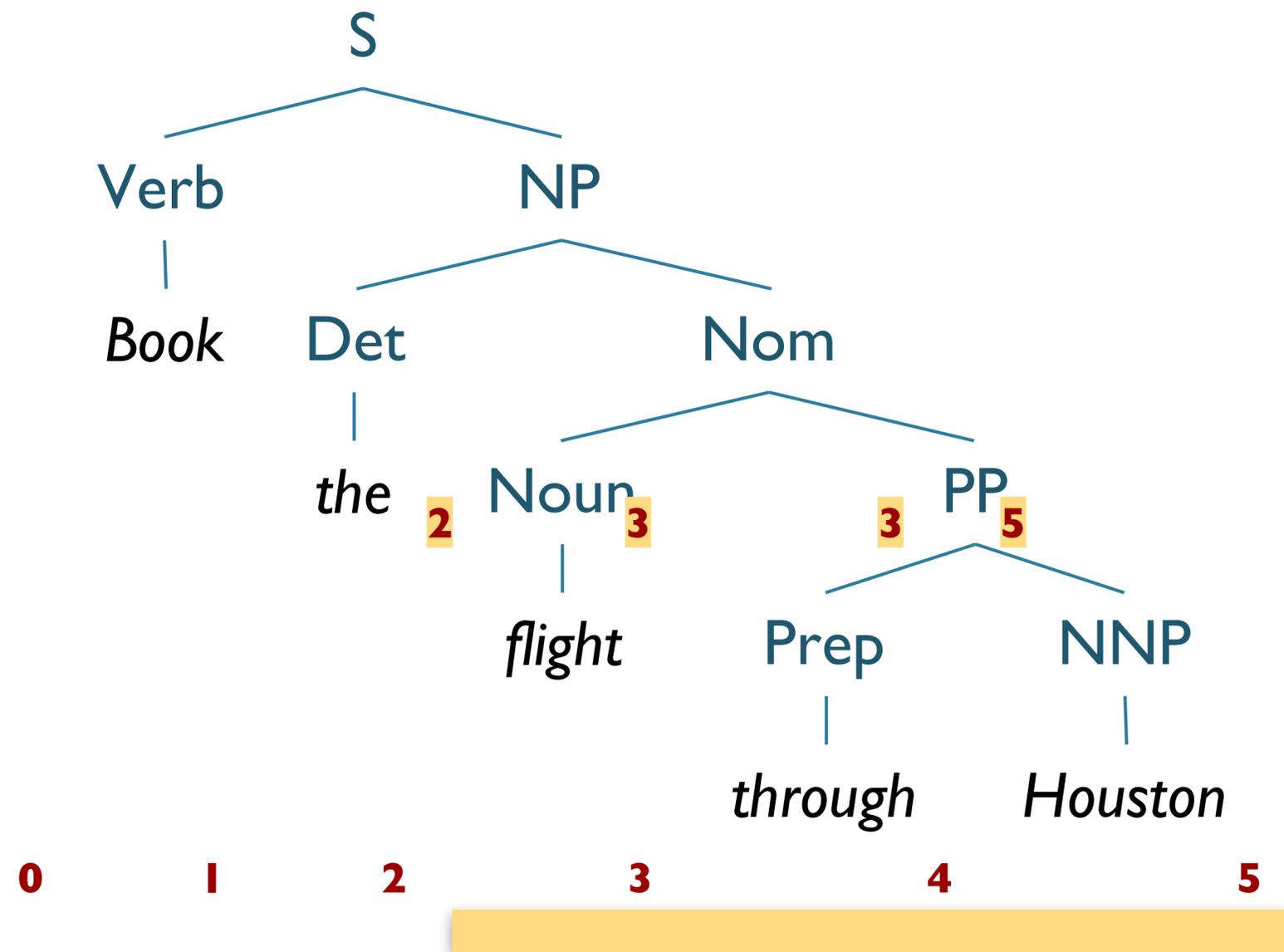
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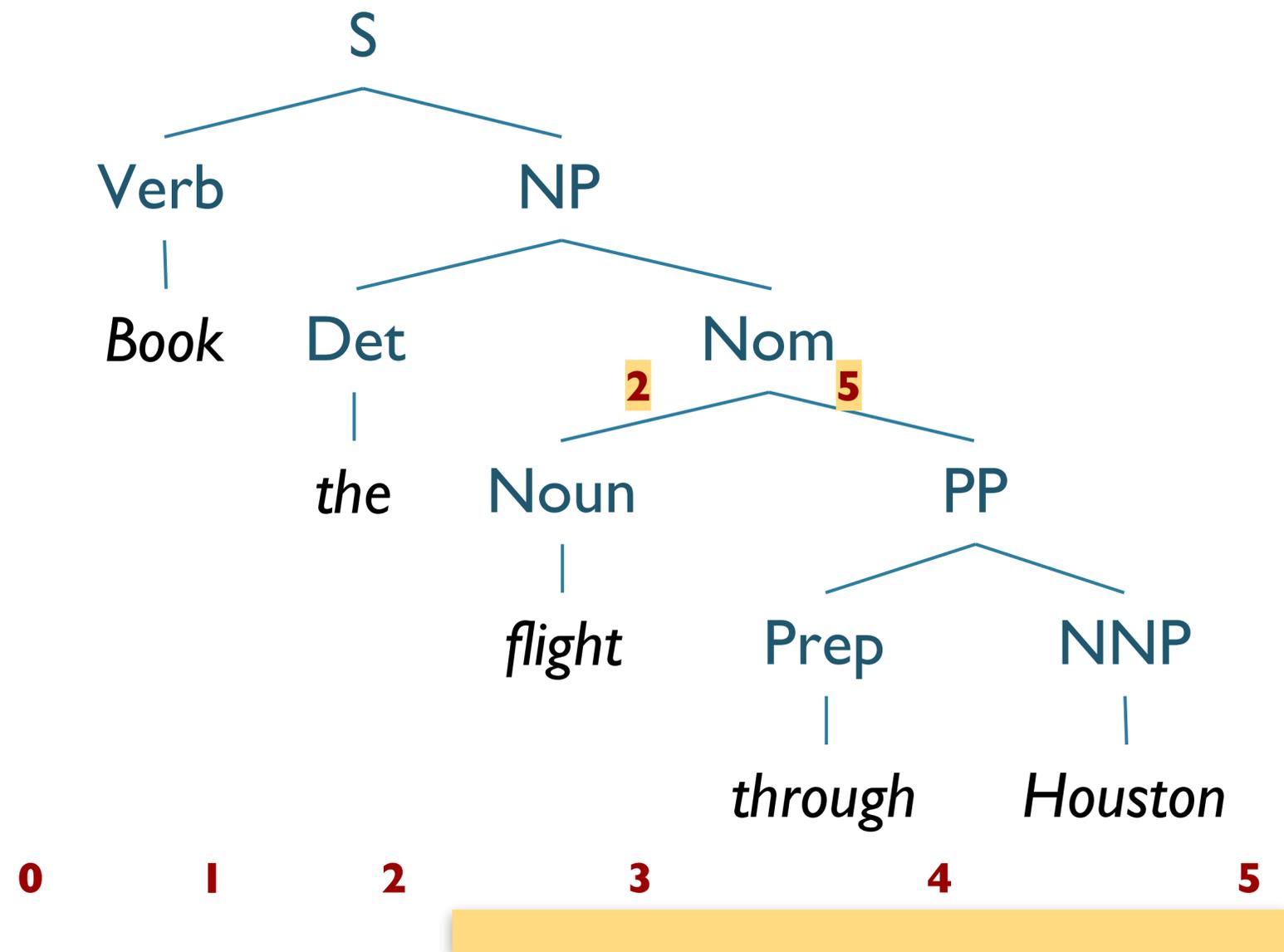
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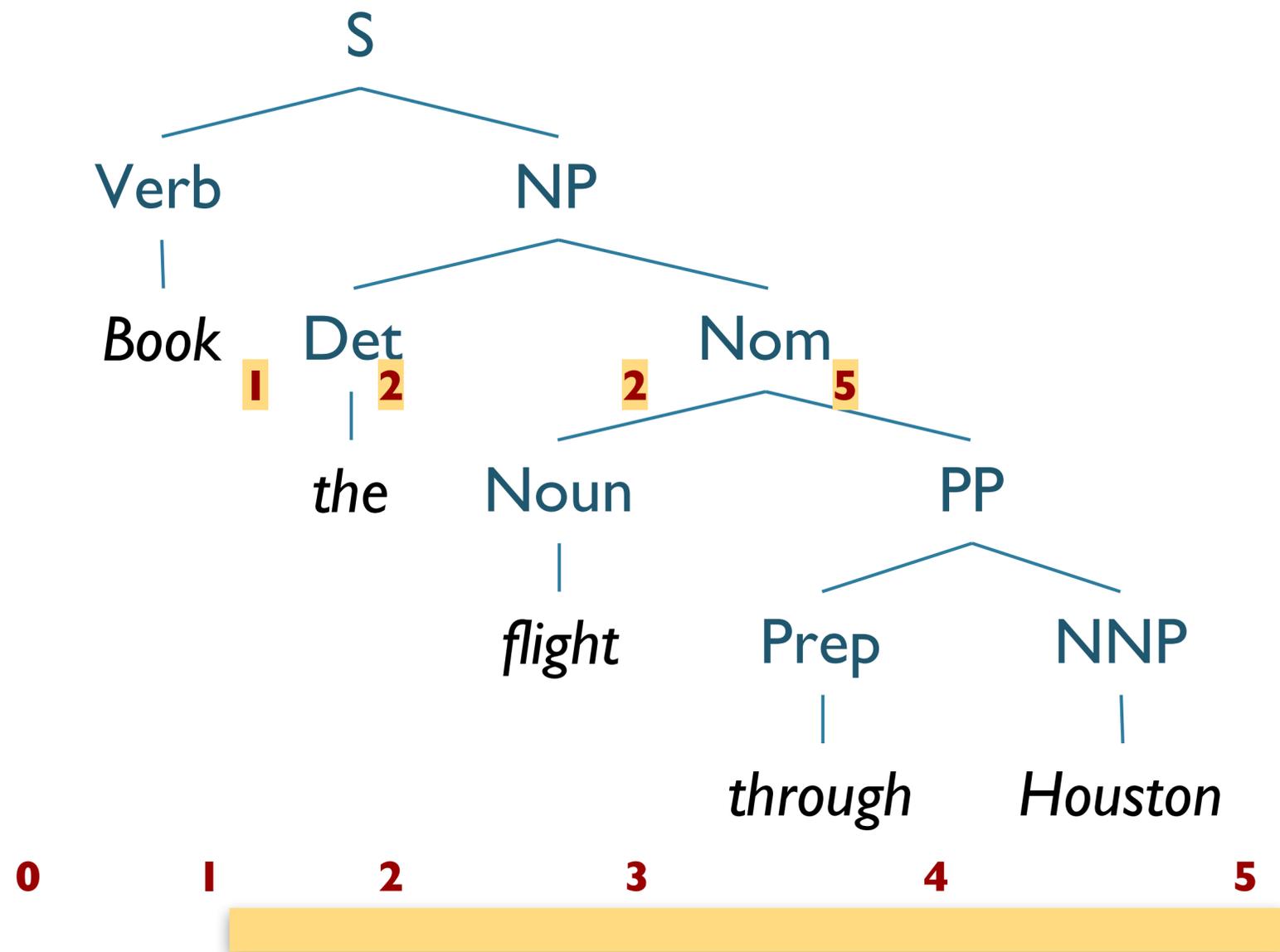
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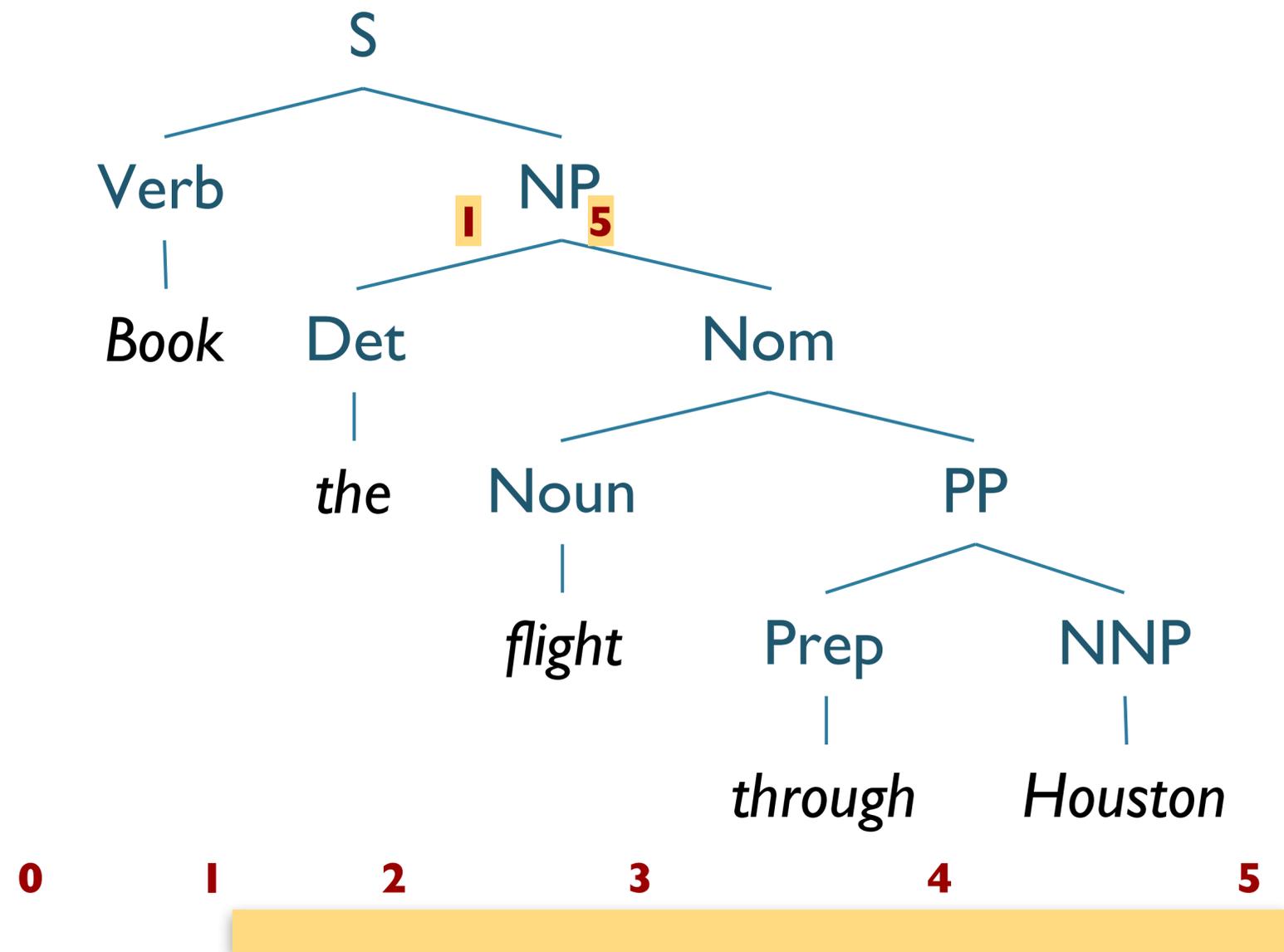
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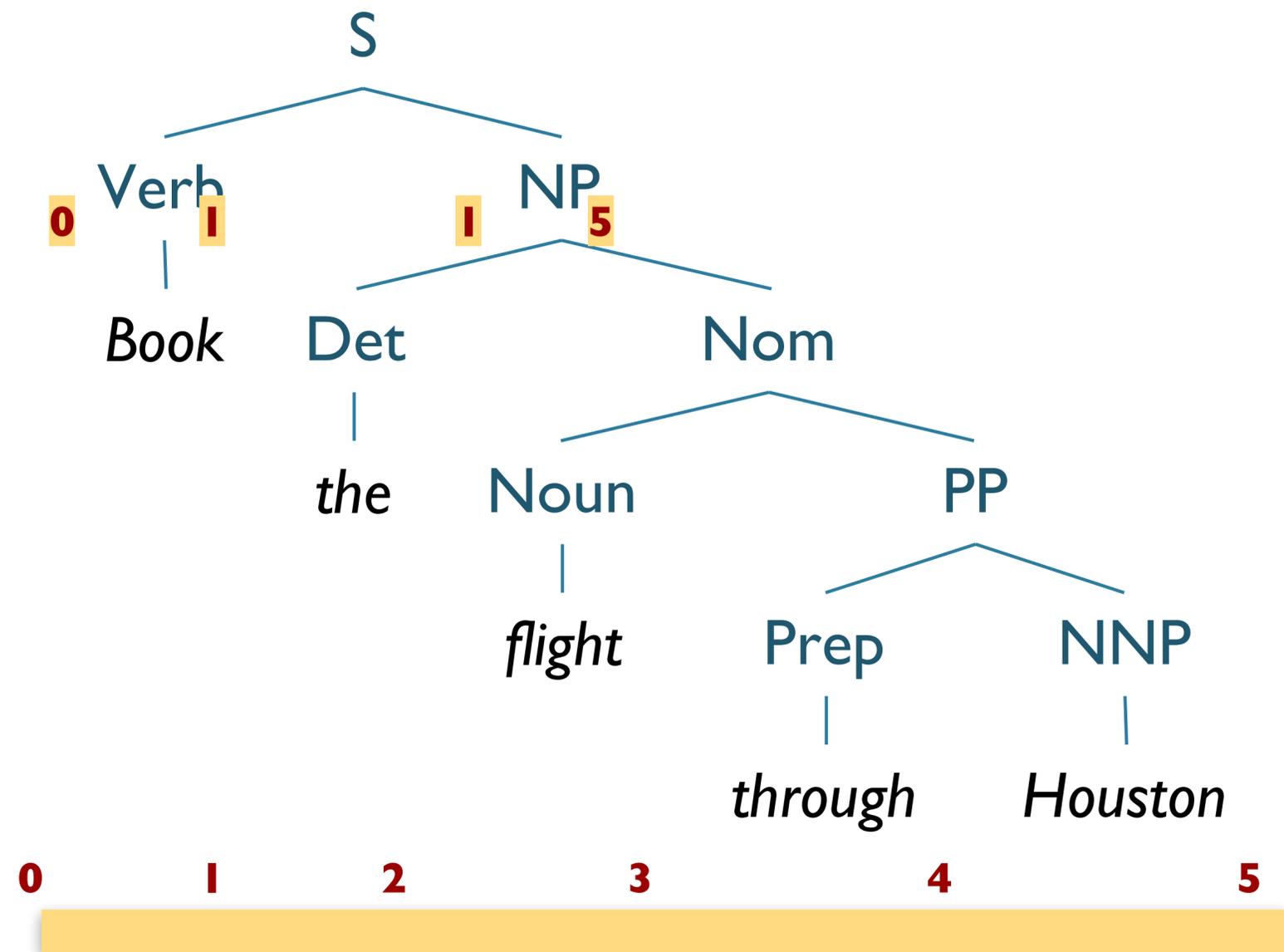
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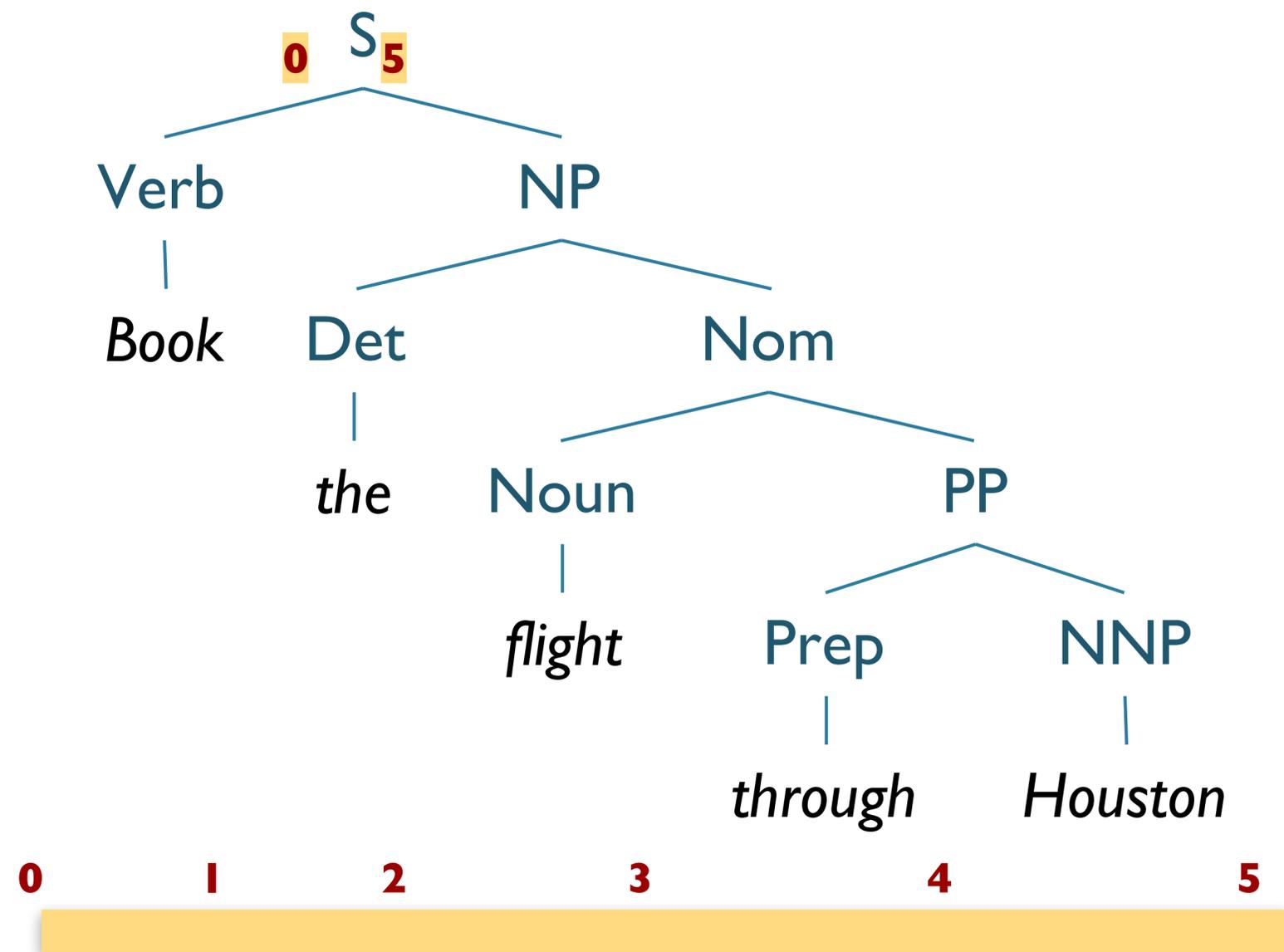
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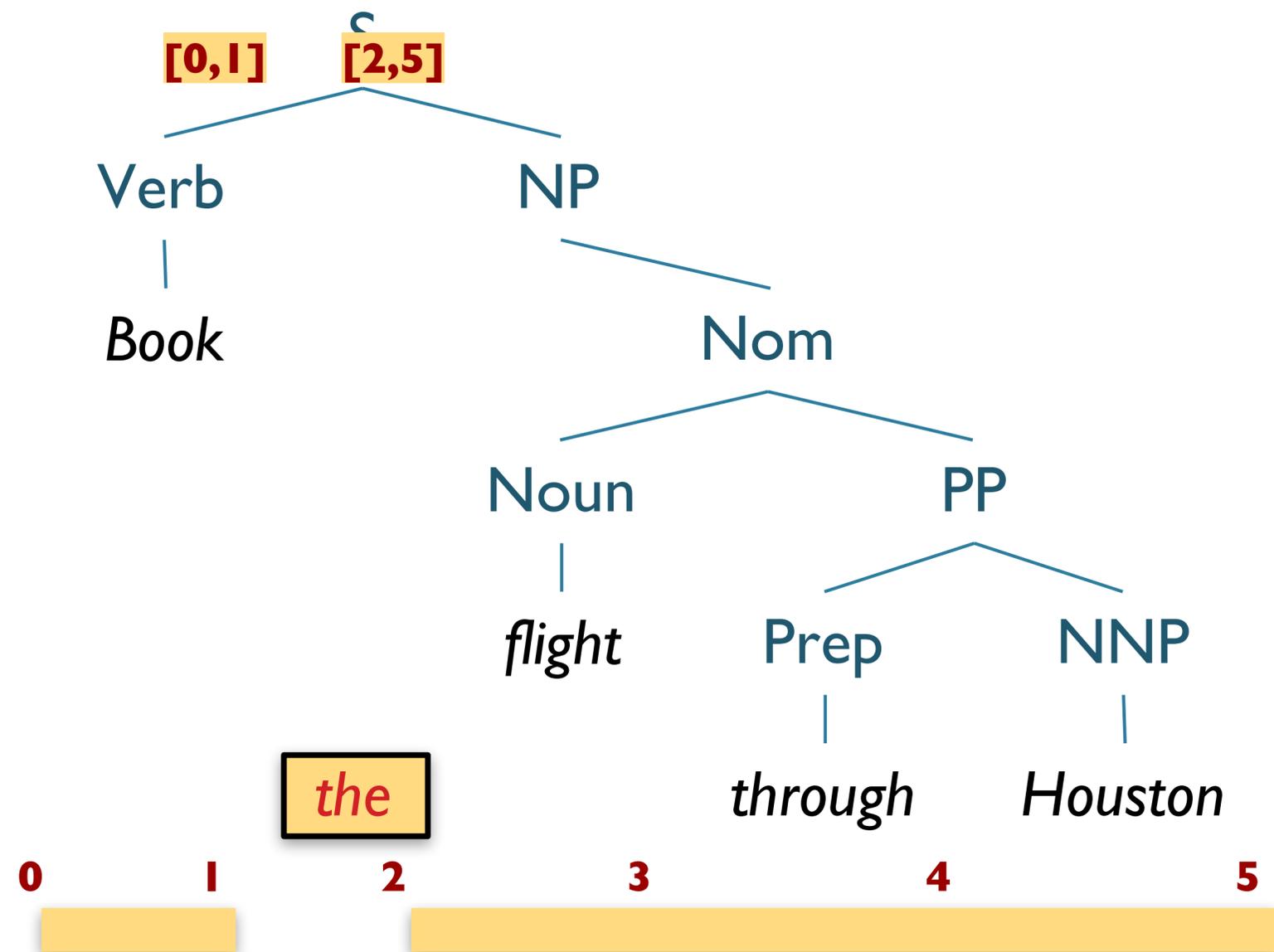
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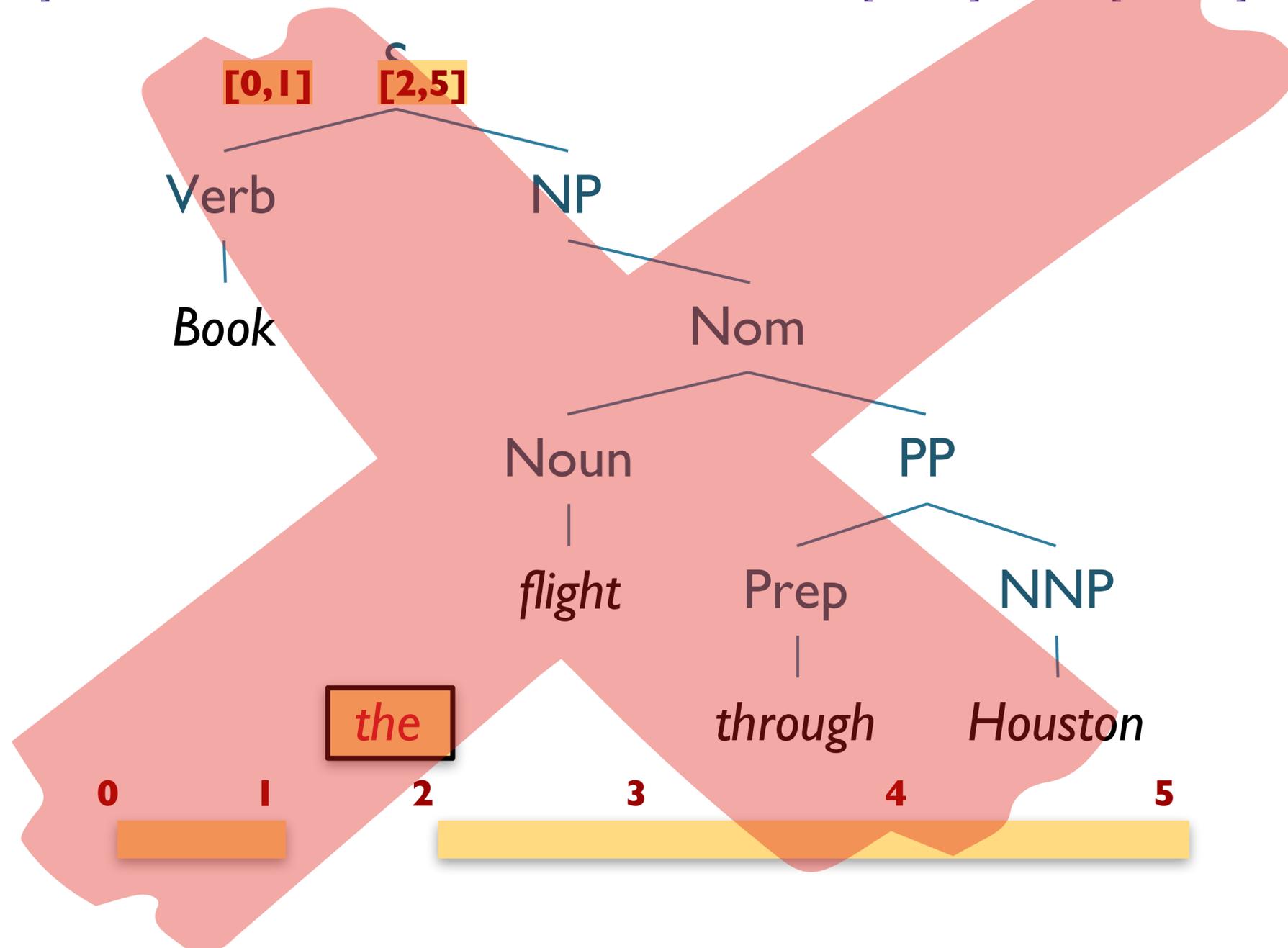
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## W Is CKY a top-down or a bottom-up parsing algorithm?

Top-down

Bottom-up

# CKY Parsing Example

**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

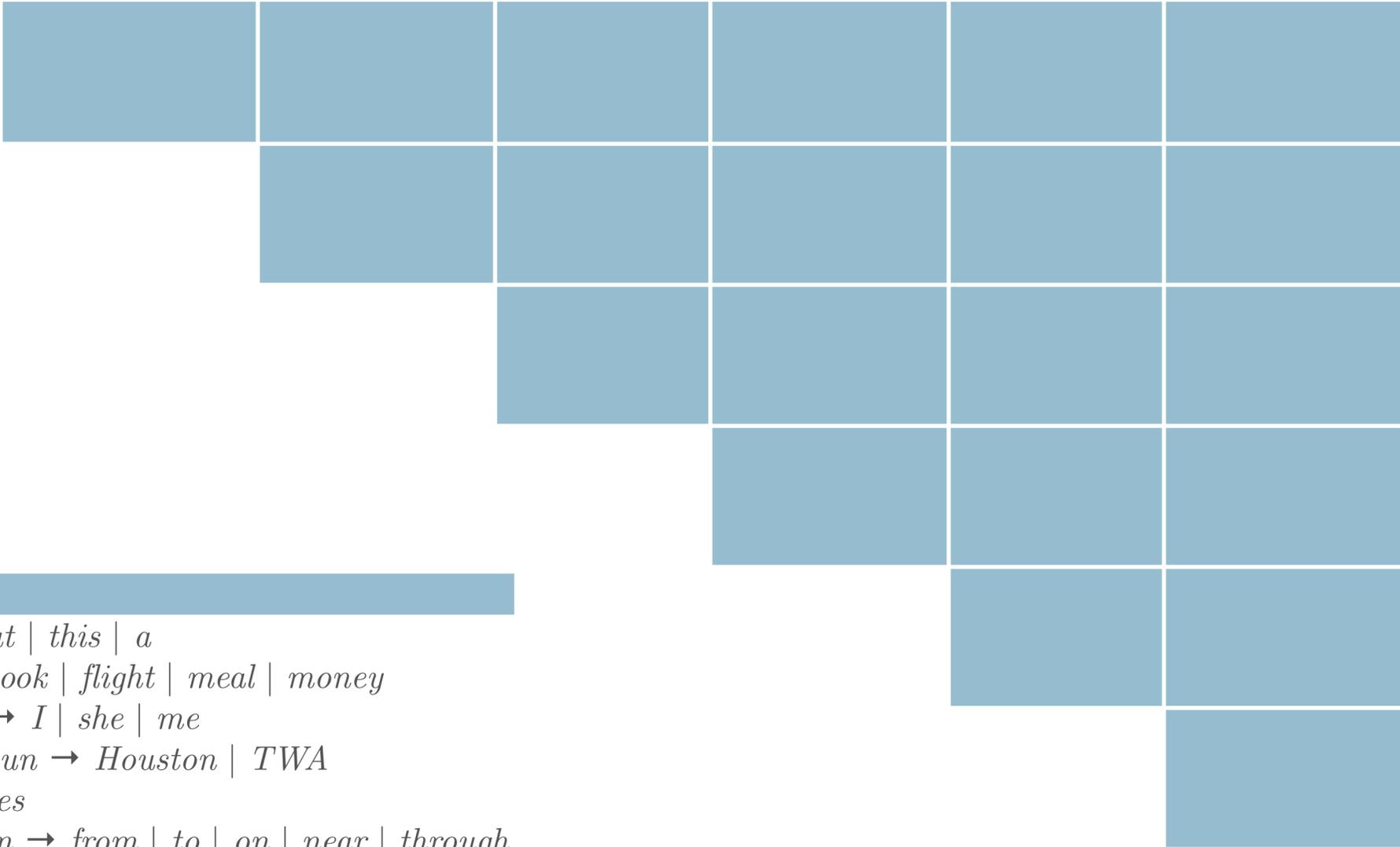
- 
- $NP \rightarrow I \mid she \mid me$
  - $NP \rightarrow TWA \mid Houston$
  - $NP \rightarrow Det Nominal$

- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

- 
- $VP \rightarrow book \mid include \mid prefer$
  - $VP \rightarrow Verb NP$
  - $VP \rightarrow X2 PP$
  - $X2 \rightarrow Verb NP$
  - $VP \rightarrow Verb PP$
  - $VP \rightarrow VP PP$
- 
- $PP \rightarrow Preposition NP$

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



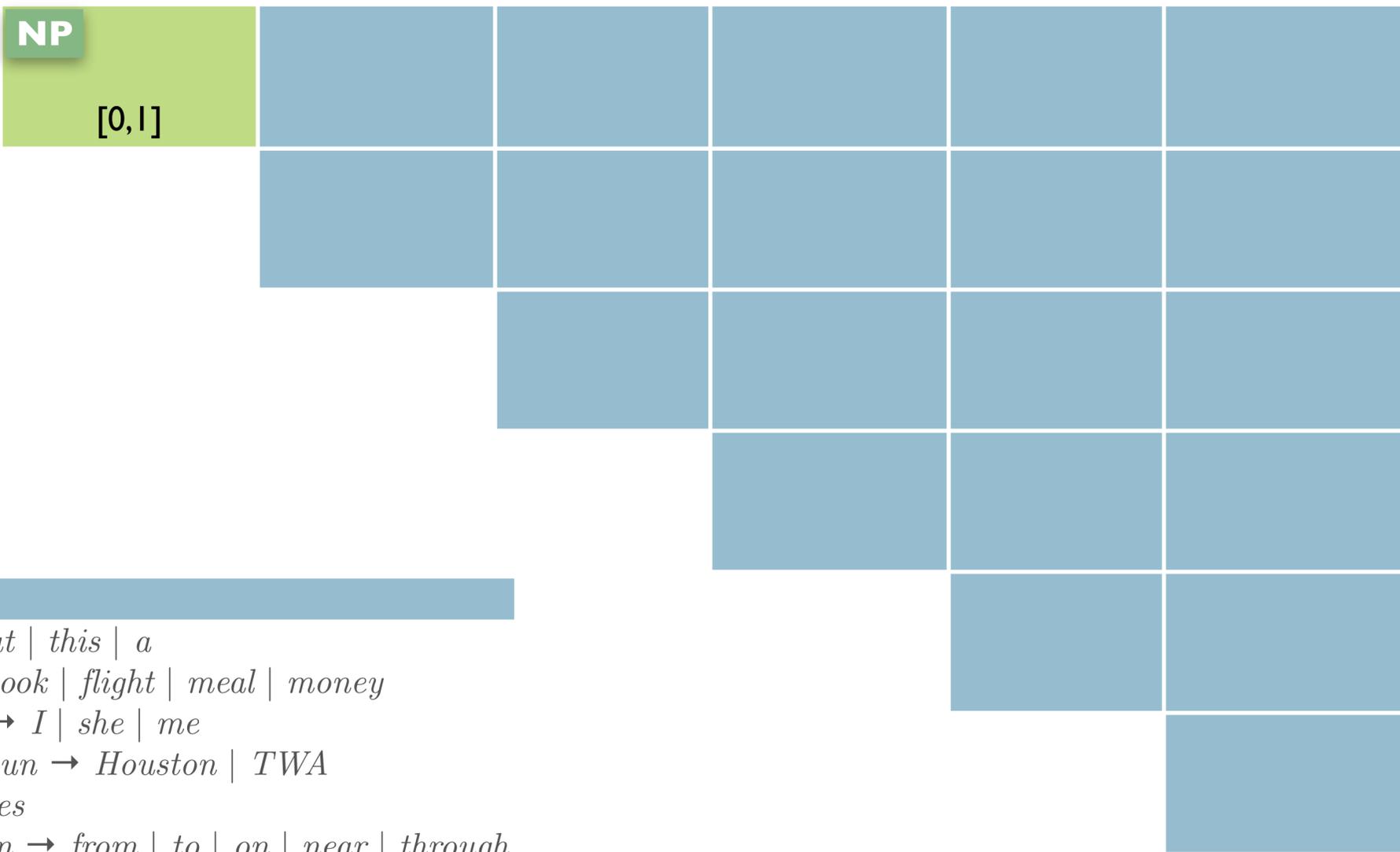
0
1
2
3
4
5
6

*I*
*prefer*
*a*
*flight*
*on*
*TWA*

**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

- 
- NP**  $\rightarrow$  **I**  $\mid$  she  $\mid$  me
  - NP  $\rightarrow$  TWA  $\mid$  Houston
  - NP  $\rightarrow$  Det Nominal
- 
- Nominal  $\rightarrow$  book  $\mid$  flight  $\mid$  meal  $\mid$  money
  - Nominal  $\rightarrow$  Nominal Noun
  - Nominal  $\rightarrow$  Nominal PP
- 
- VP  $\rightarrow$  book  $\mid$  include  $\mid$  prefer
  - VP  $\rightarrow$  Verb NP
  - VP  $\rightarrow$  X2 PP
  - X2  $\rightarrow$  Verb NP
  - VP  $\rightarrow$  Verb PP
  - VP  $\rightarrow$  VP PP
- 
- PP  $\rightarrow$  Preposition NP



**Lexicon**

- Det  $\rightarrow$  that  $\mid$  this  $\mid$  a
- Noun  $\rightarrow$  book  $\mid$  flight  $\mid$  meal  $\mid$  money
- Pronoun  $\rightarrow$  I  $\mid$  she  $\mid$  me
- Proper-Noun  $\rightarrow$  Houston  $\mid$  TWA
- Aux  $\rightarrow$  does
- Preposition  $\rightarrow$  from  $\mid$  to  $\mid$  on  $\mid$  near  $\mid$  through
- Verb  $\rightarrow$  book  $\mid$  include  $\mid$  prefer



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

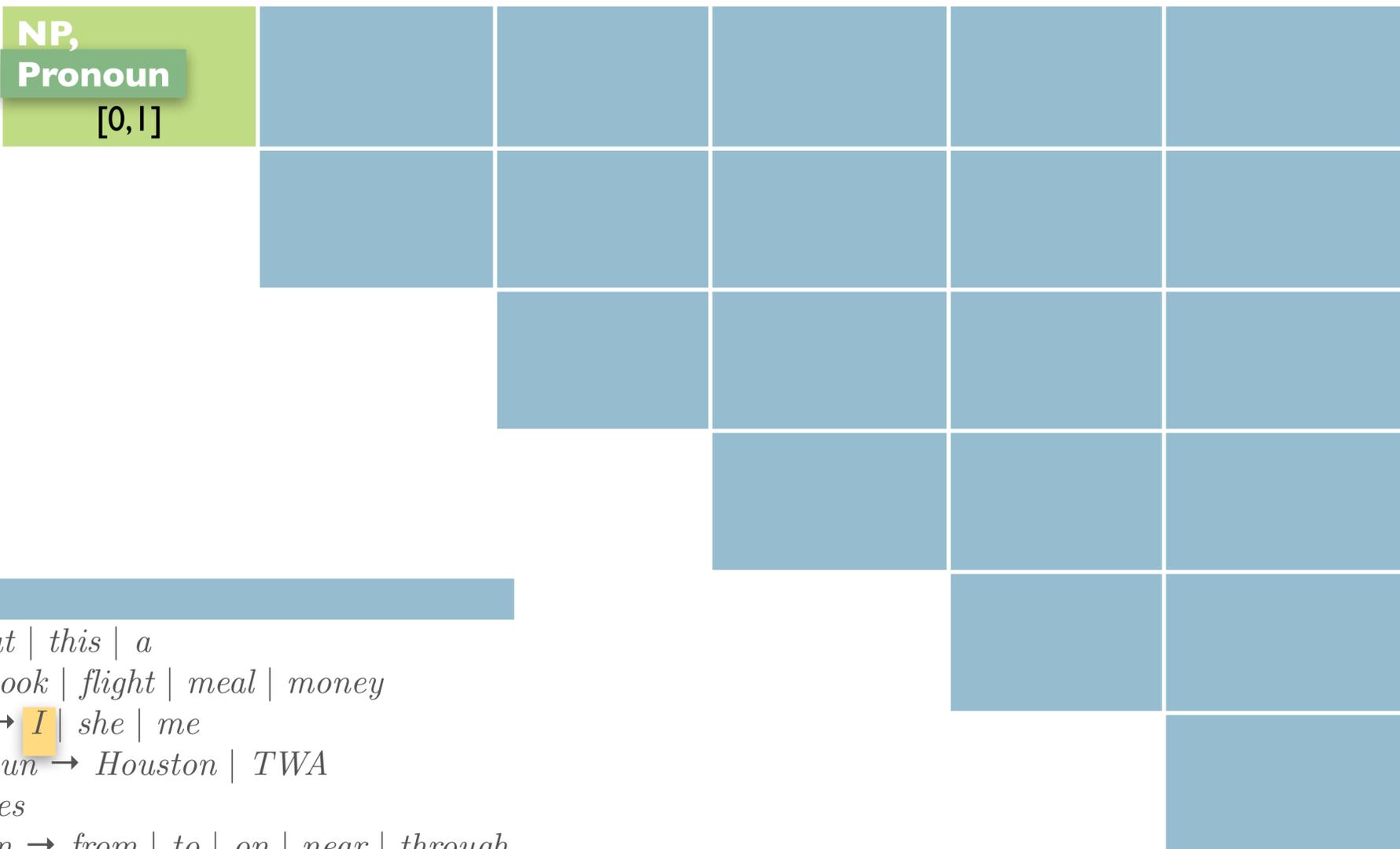
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

---

- $PP \rightarrow Preposition NP$



**Lexicon**

- $Det \rightarrow that \mid this \mid a$
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- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book / include / prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I / she / me$
- $NP \rightarrow TWA / Houston$
- $NP \rightarrow Det Nominal$

---

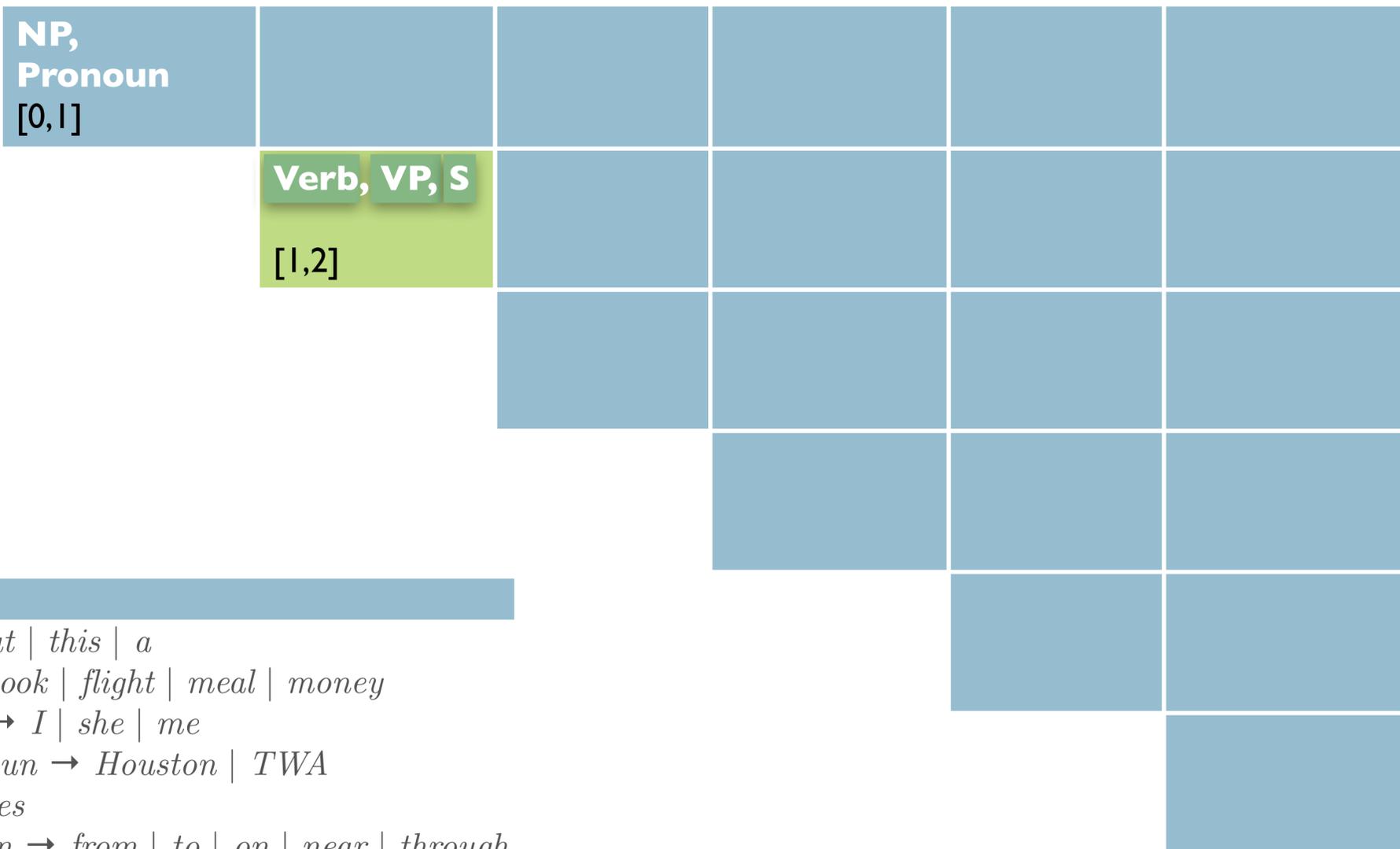
- $Nominal \rightarrow book / flight / meal / money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book / include / prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

---

- $PP \rightarrow Preposition NP$



**Lexicon**

- Det*  $\rightarrow that | this | a$
- Noun*  $\rightarrow book | flight | meal | money$
- Pronoun*  $\rightarrow I | she | me$
- Proper-Noun*  $\rightarrow Houston | TWA$
- Aux*  $\rightarrow does$
- Preposition*  $\rightarrow from | to | on | near | through$
- Verb**  $\rightarrow book | include | prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

- 
- $NP \rightarrow I \mid she \mid me$
  - $NP \rightarrow TWA \mid Houston$
  - $NP \rightarrow Det Nominal$

- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

- 
- $VP \rightarrow book \mid include \mid prefer$
  - $VP \rightarrow Verb NP$
  - $VP \rightarrow X2 PP$
  - $X2 \rightarrow Verb NP$
  - $VP \rightarrow Verb PP$
  - $VP \rightarrow VP PP$
  - $PP \rightarrow Preposition NP$

NP, NP, Pronoun [0,1]	[0,2]				
	Verb, VP, S [1,2]				

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
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- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

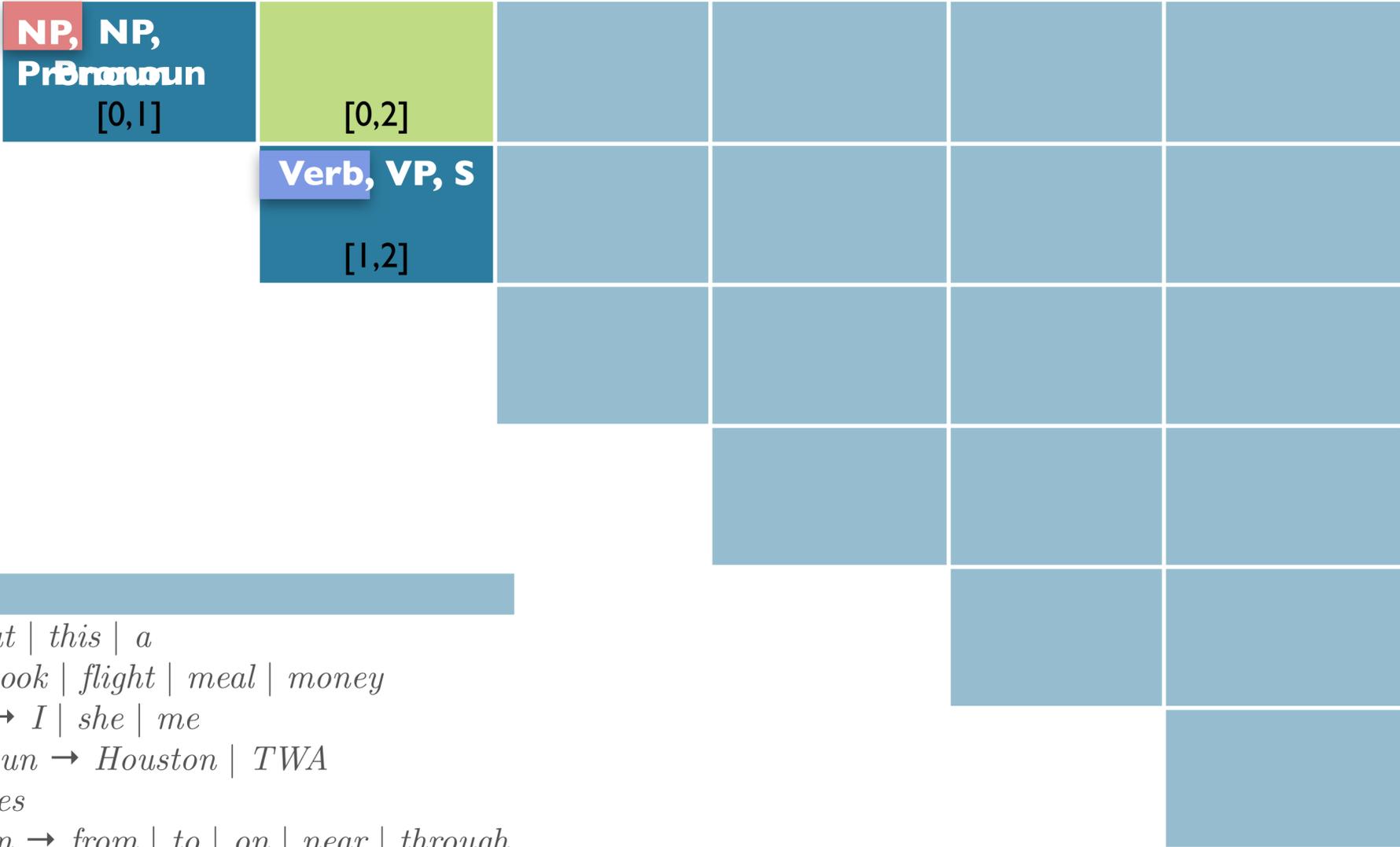
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

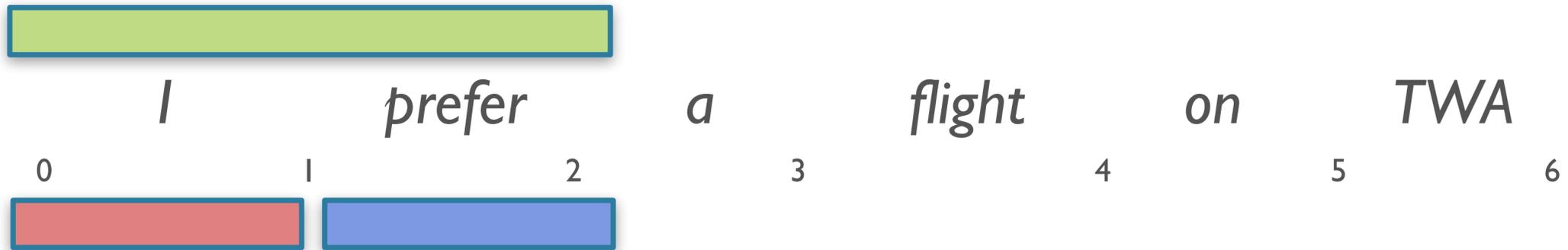
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- $PP \rightarrow Preposition NP$



**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
- Pronoun* → I | she | me
- Proper-Noun* → Houston | TWA
- Aux* → does
- Preposition* → from | to | on | near | through
- Verb* → book | include | prefer



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

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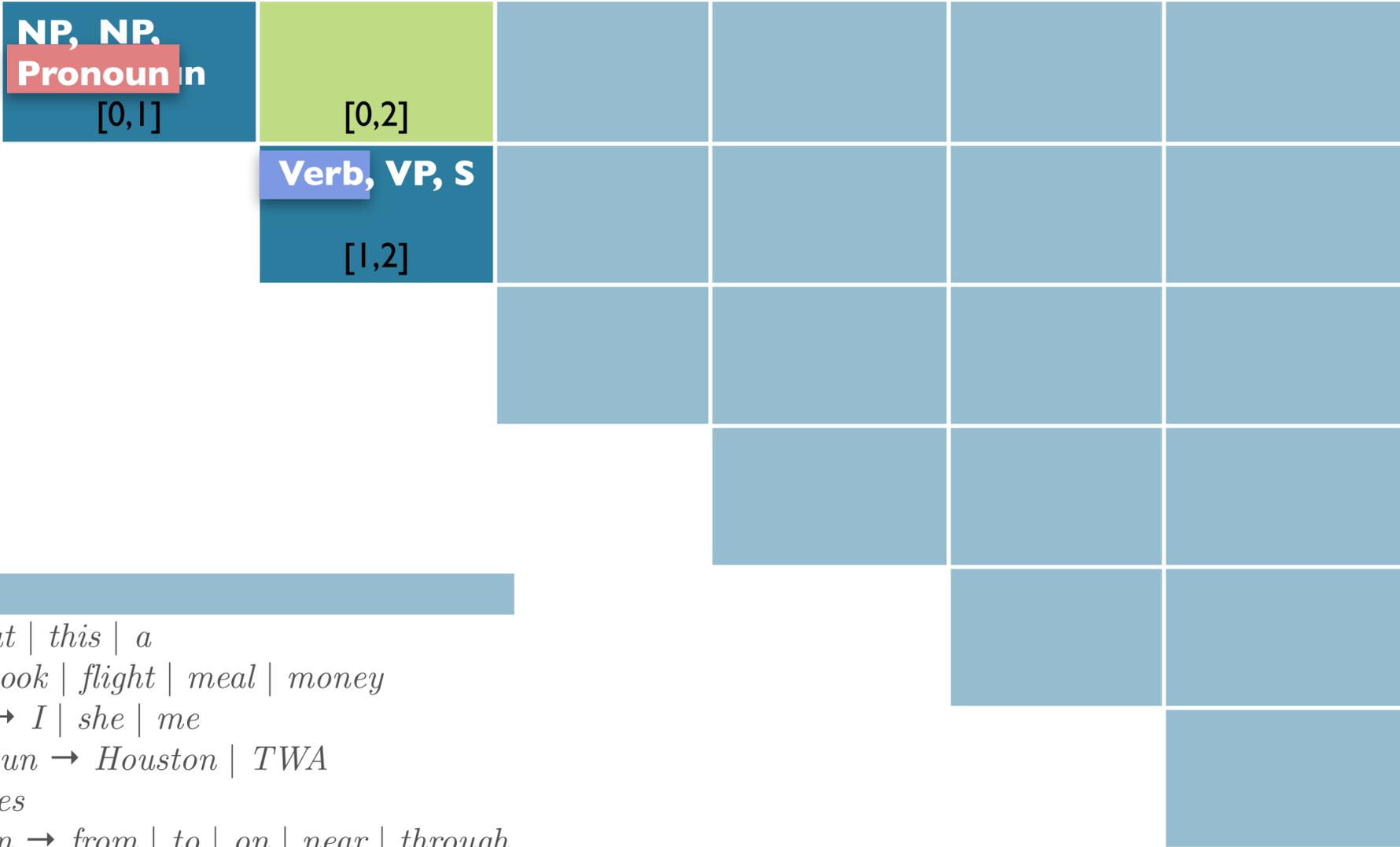
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

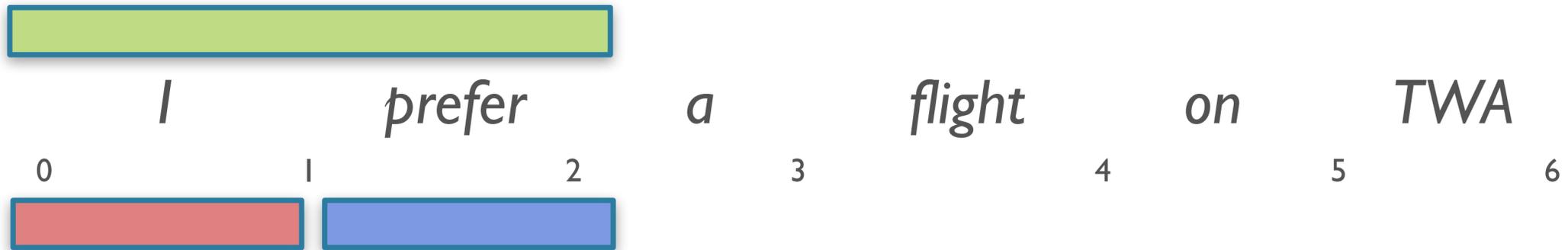
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- $PP \rightarrow Preposition NP$



**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
- Pronoun* → I | she | me
- Proper-Noun* → Houston | TWA
- Aux* → does
- Preposition* → from | to | on | near | through
- Verb* → book | include | prefer



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

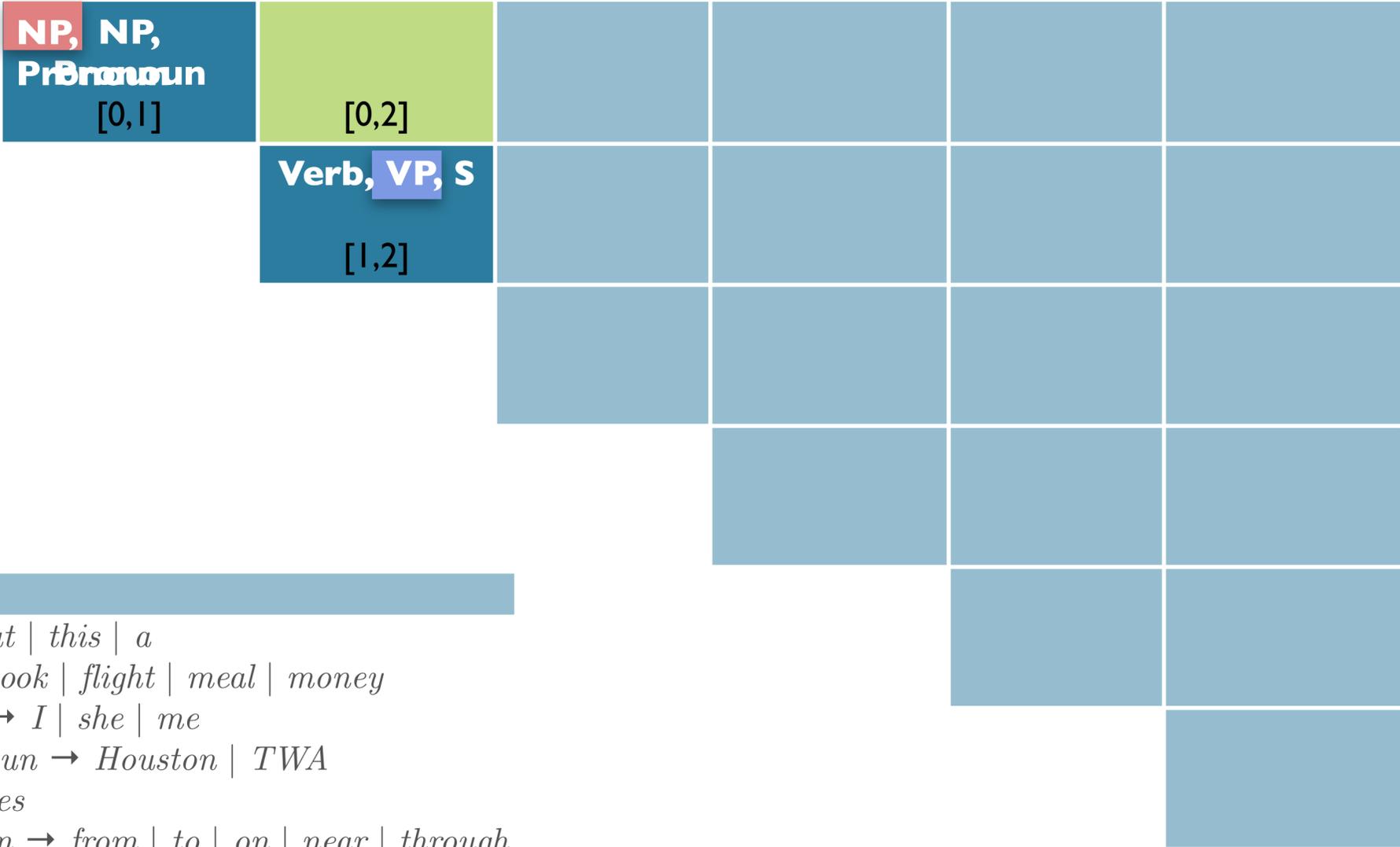
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

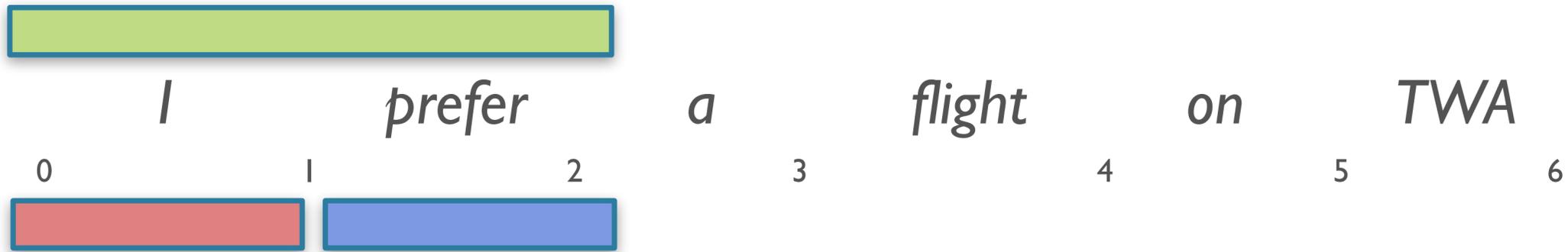
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- $PP \rightarrow Preposition NP$



**Lexicon**

- Det*  $\rightarrow that \mid this \mid a$
- Noun*  $\rightarrow book \mid flight \mid meal \mid money$
- Pronoun*  $\rightarrow I \mid she \mid me$
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- Aux*  $\rightarrow does$
- Preposition*  $\rightarrow from \mid to \mid on \mid near \mid through$
- Verb*  $\rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- S** → **NP** **VP**
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

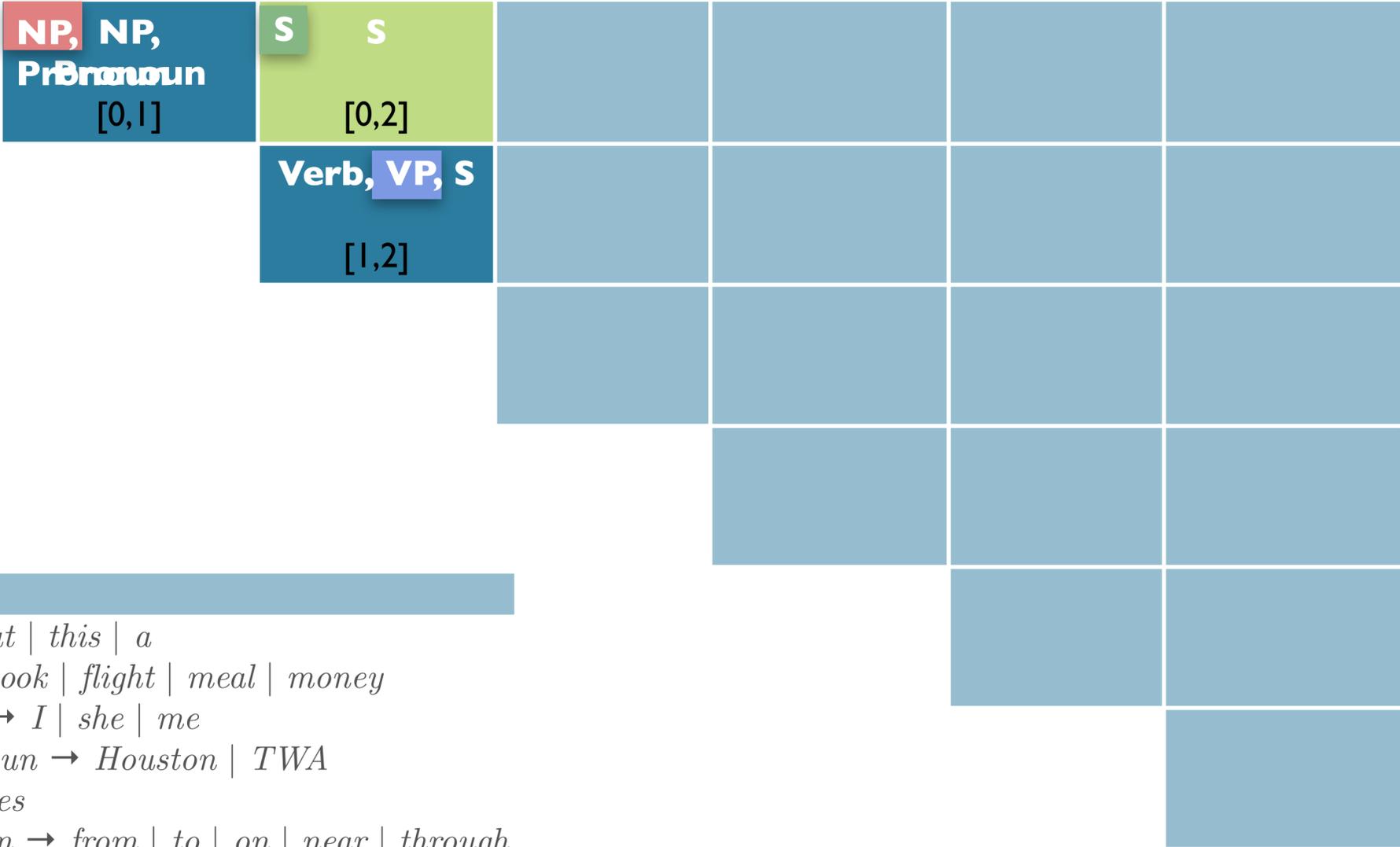
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

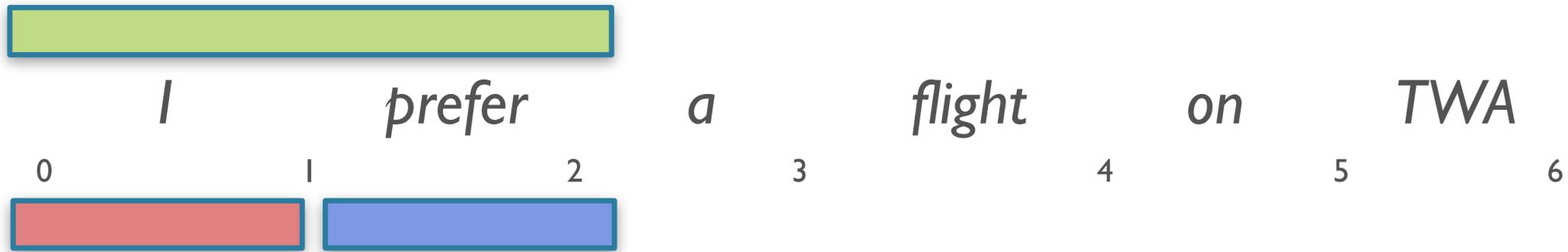
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- $PP \rightarrow Preposition NP$



**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
- Pronoun* → I | she | me
- Proper-Noun* → Houston | TWA
- Aux* → does
- Preposition* → from | to | on | near | through
- Verb* → book | include | prefer



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

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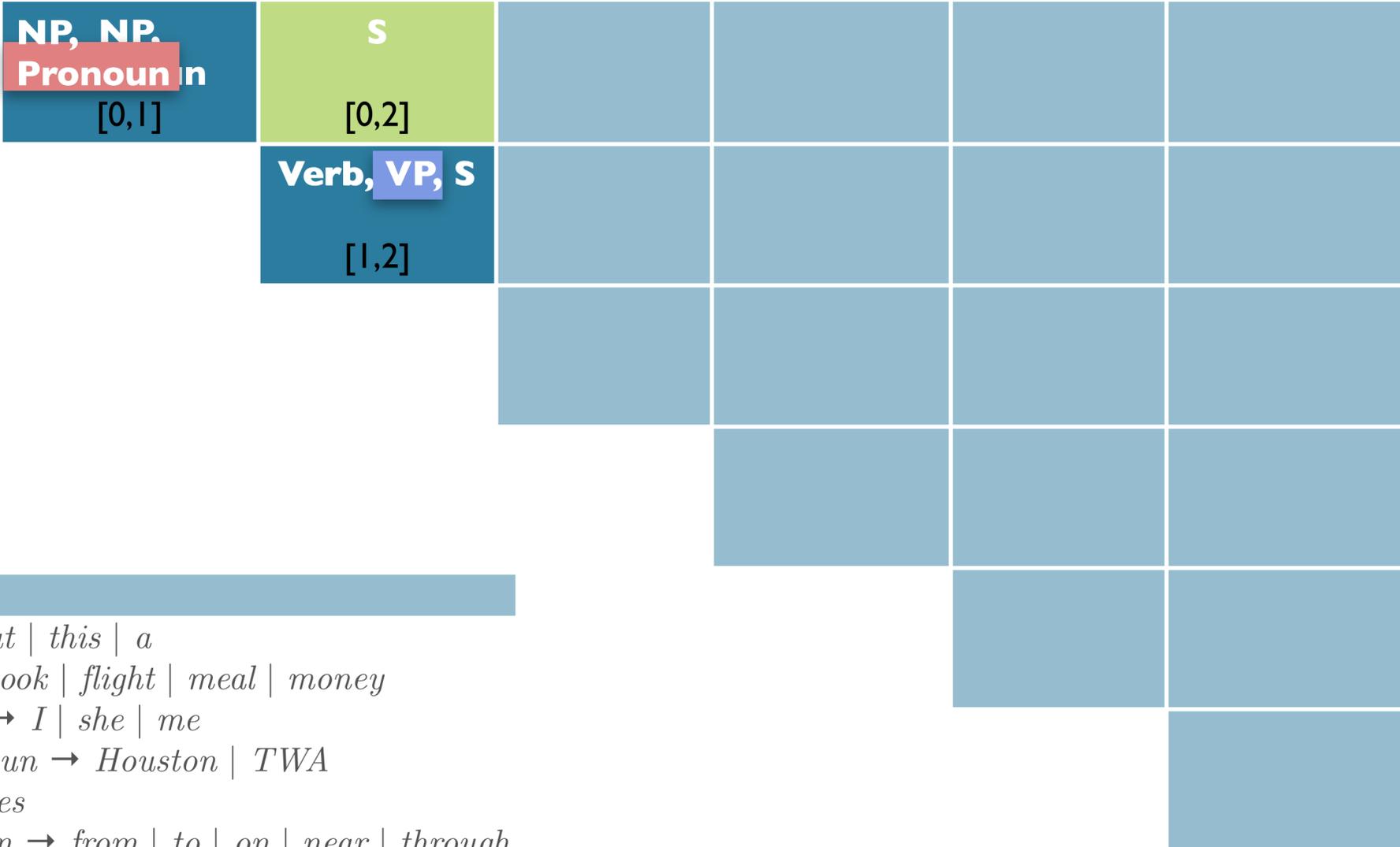
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

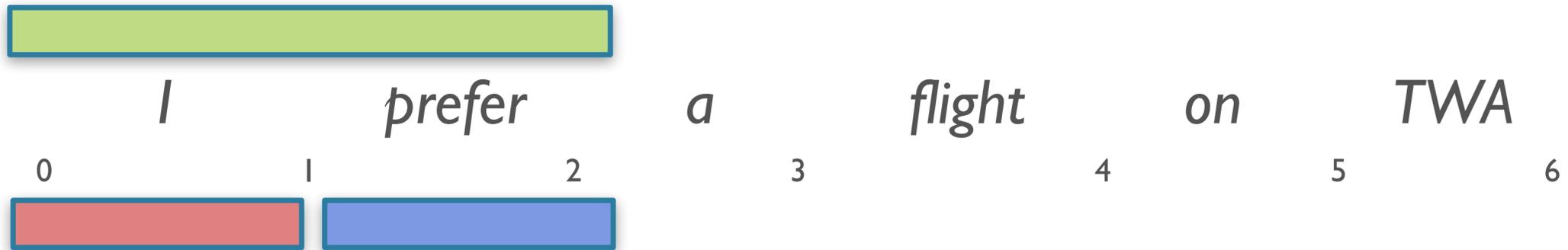
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- $PP \rightarrow Preposition NP$



**Lexicon**

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- Preposition* → from | to | on | near | through
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- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
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- $S \rightarrow X2 PP$
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---

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---

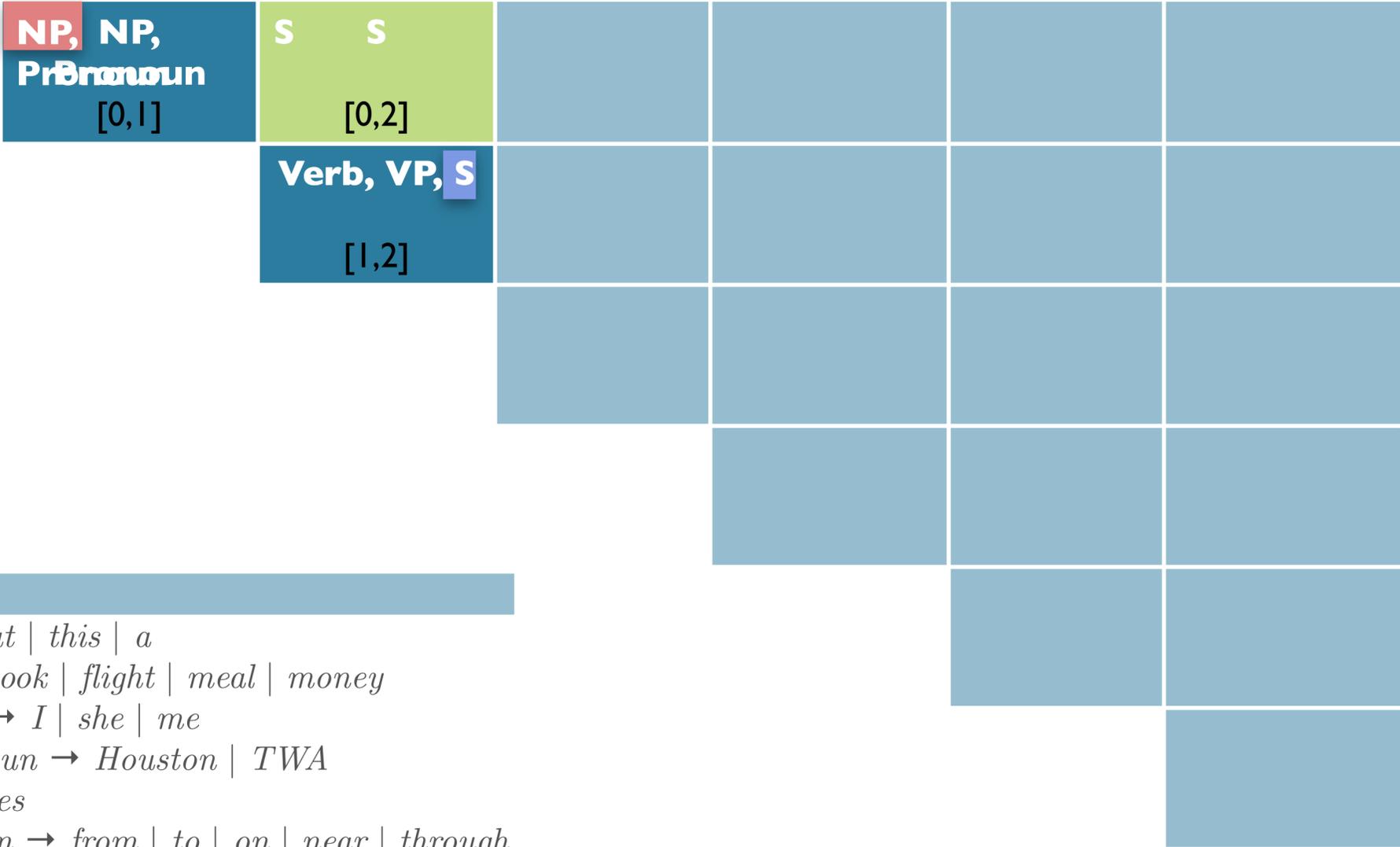
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
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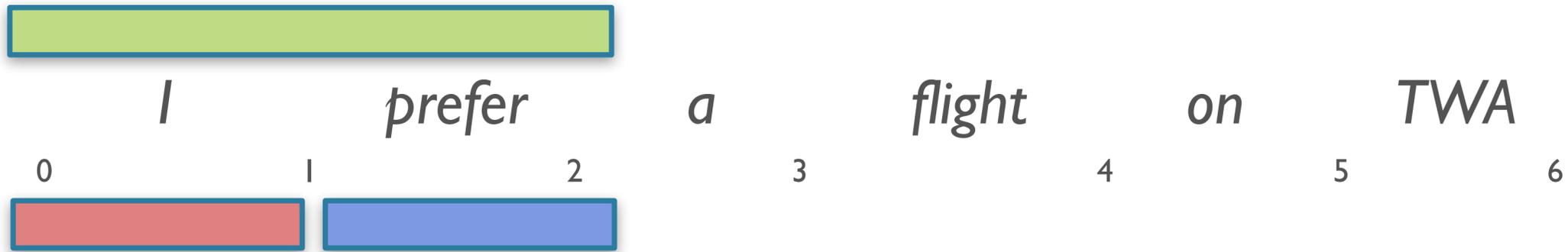
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- $PP \rightarrow Preposition NP$



**Lexicon**

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**$\mathcal{L}_1$  Grammar**

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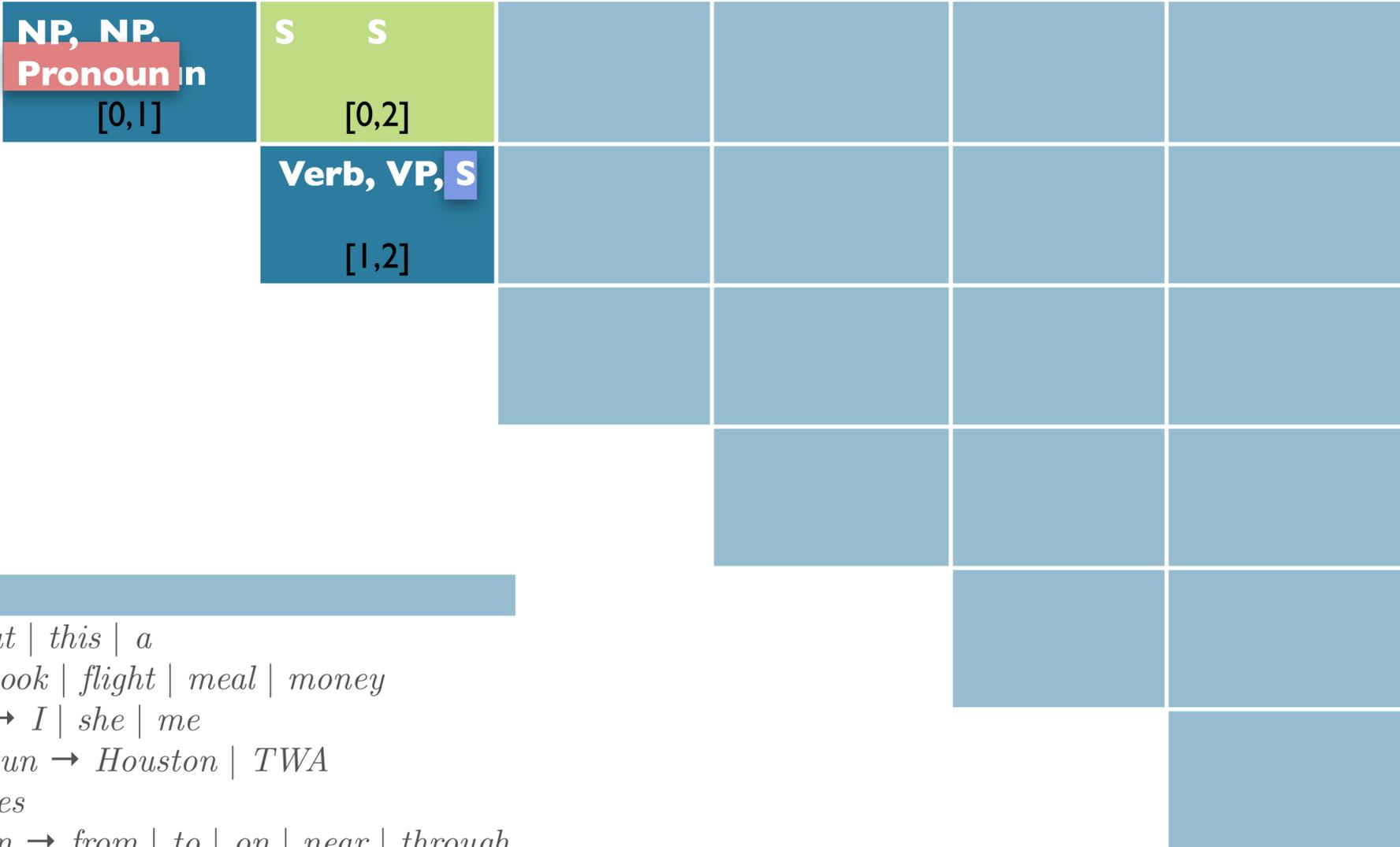
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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---

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- $VP \rightarrow Verb PP$
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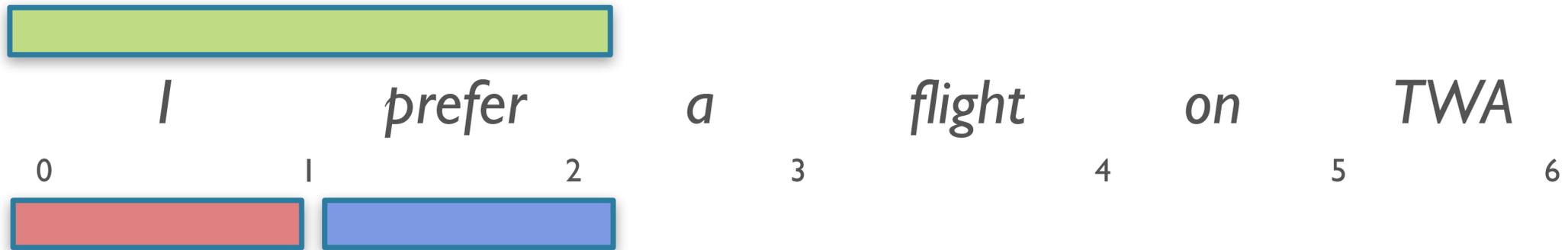
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- $PP \rightarrow Preposition NP$



**Lexicon**

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**$\mathcal{L}_1$  Grammar**

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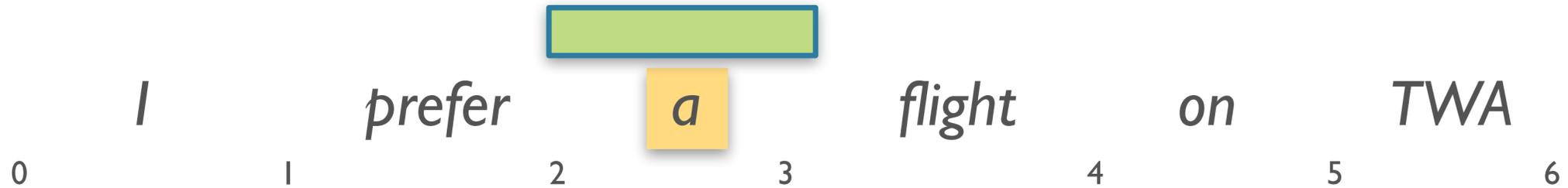
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- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]				
	<b>Verb, VP, S</b> [1,2]				
		<b>Det</b> [2,3]			

**Lexicon**

- Det**  $\rightarrow that \mid this \mid a$
- Noun**  $\rightarrow book \mid flight \mid meal \mid money$
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- Aux**  $\rightarrow does$
- Preposition**  $\rightarrow from \mid to \mid on \mid near \mid through$
- Verb**  $\rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
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- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
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- $S \rightarrow VP PP$

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- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

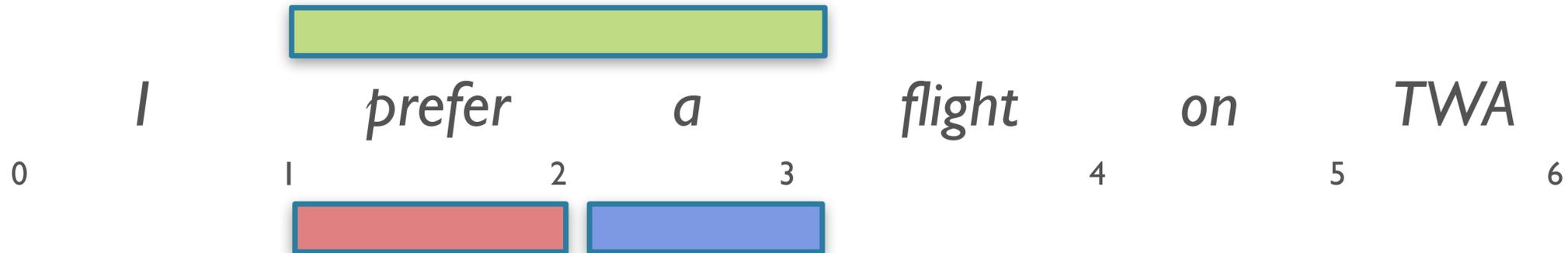
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
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- $PP \rightarrow Preposition NP$

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- $Verb \rightarrow book \mid include \mid prefer$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]				
	<b>Verb, VP, S</b> [1,2]	[1,3]			
		<b>Det</b> [2,3]			



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
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- $S \rightarrow VP PP$

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  - $NP \rightarrow TWA \mid Houston$
  - $NP \rightarrow Det Nominal$

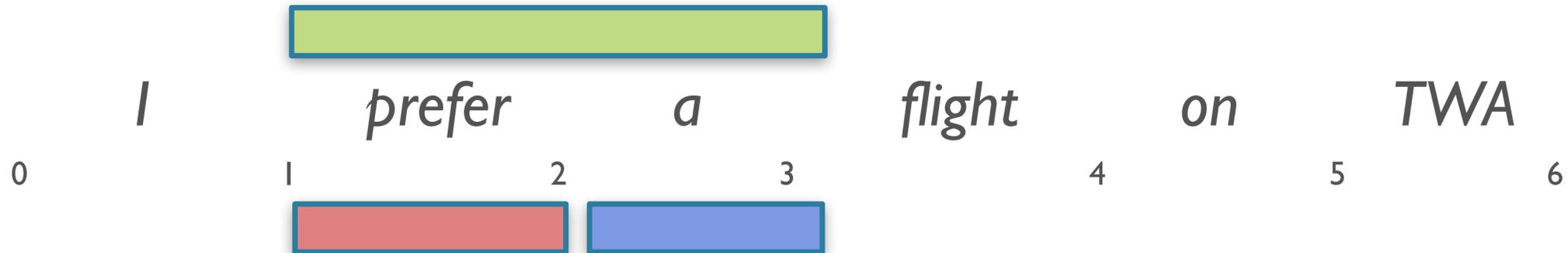
- 
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
  - $Nominal \rightarrow Nominal Noun$
  - $Nominal \rightarrow Nominal PP$

- 
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  - $VP \rightarrow Verb NP$
  - $VP \rightarrow X2 PP$
  - $X2 \rightarrow Verb NP$
  - $VP \rightarrow Verb PP$
  - $VP \rightarrow VP PP$
  - $PP \rightarrow Preposition NP$

**Lexicon**

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- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]				
	<b>Verb, VP, S</b> [1,2]				
		<b>Det Det</b> [1,3]			



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
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- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

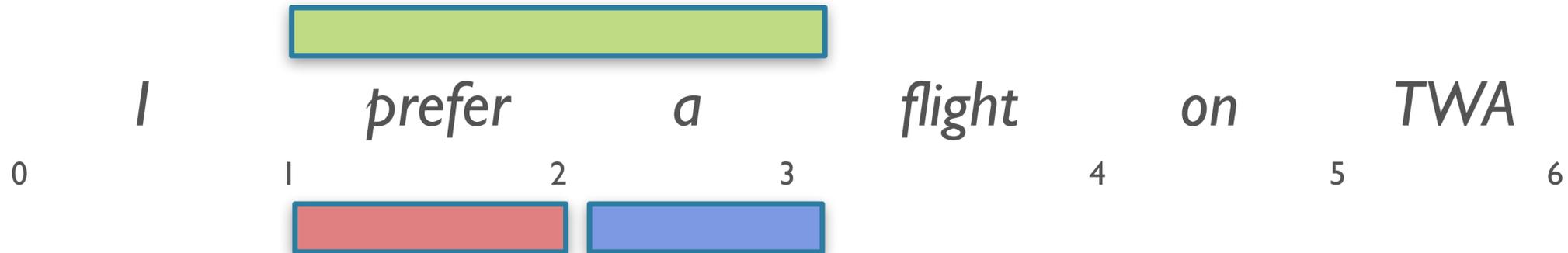
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- $VP \rightarrow book \mid include \mid prefer$
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- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
- $PP \rightarrow Preposition NP$

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]				
	<b>Verb, VP, S</b> [1,2]				
		<b>Det Det</b> [1,3]			
			<b>Det Det</b> [2,3]		



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

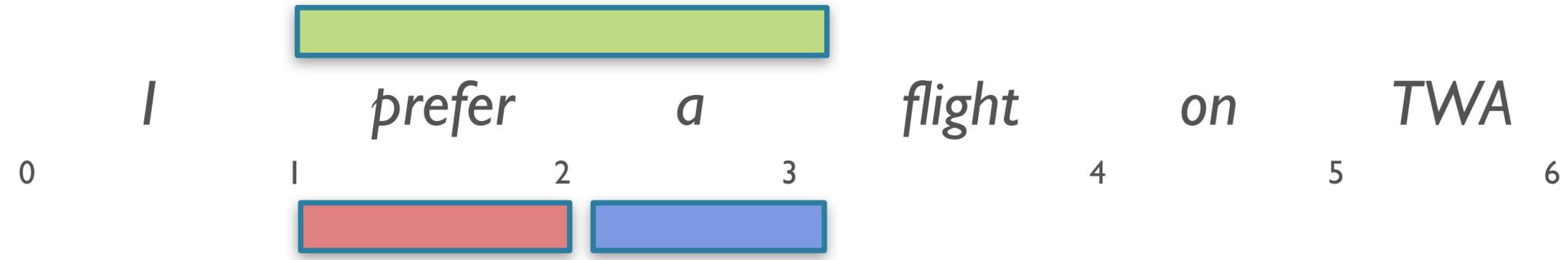
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]				
	<b>Verb, VP, S</b> [1,2]	<b>Det</b> [1,3]			
		<b>Det Det</b> [2,3]			

**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
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- Proper-Noun* → Houston | TWA
- Aux* → does
- Preposition* → from | to | on | near | through
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**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
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- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $NP \rightarrow I \mid she \mid me$
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---

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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

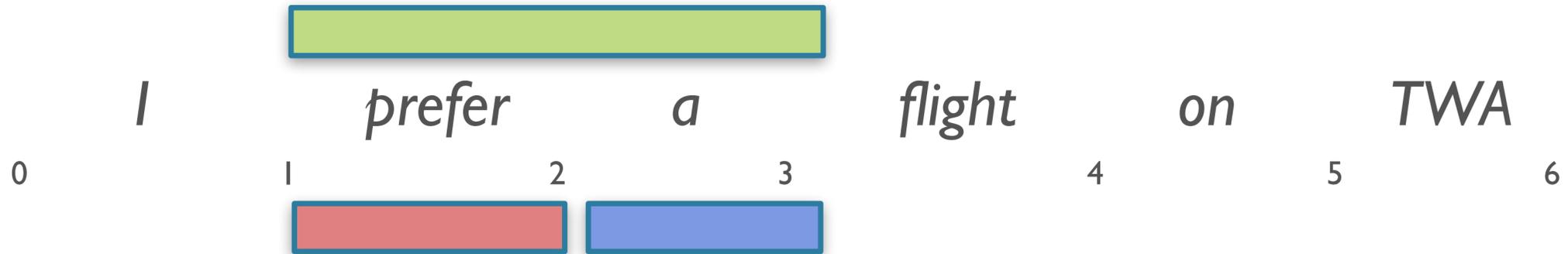
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun [0,1]</b>	<b>S [0,2]</b>				
	<b>Verb, VP, S [1,2]</b>	<b>[1,3]</b>			
	<b>Det [2,3]</b>				

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**$\mathcal{L}_1$  Grammar**

$S \rightarrow NP VP$   
 $S \rightarrow X1 VP$   
 $X1 \rightarrow Aux NP$   
 $S \rightarrow book \mid include \mid prefer$   
 $S \rightarrow Verb NP$   
 $S \rightarrow X2 PP$   
 $S \rightarrow Verb PP$   
 $S \rightarrow VP PP$

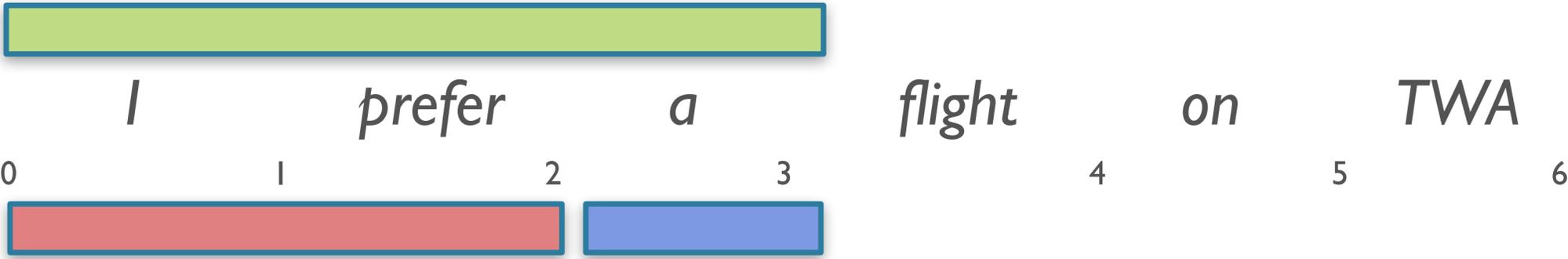
$NP \rightarrow I \mid she \mid me$   
 $NP \rightarrow TWA \mid Houston$   
 $NP \rightarrow Det Nominal$   
 $Nominal \rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$   
 $Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$   
 $VP \rightarrow Verb NP$   
 $VP \rightarrow X2 PP$   
 $X2 \rightarrow Verb NP$   
 $VP \rightarrow Verb PP$   
 $VP \rightarrow VP PP$   
 $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]			
		<b>Det</b> [2,3]			

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- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

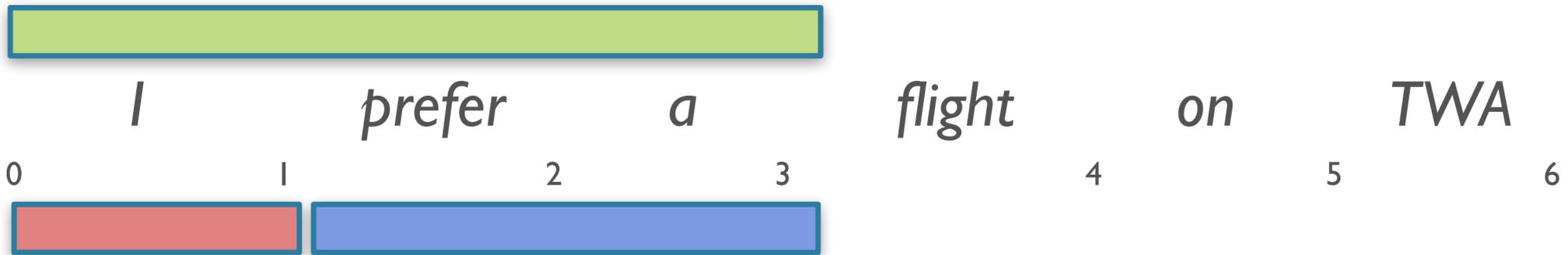
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
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NP, Pronoun [0,1]	S [0,2]	[0,3]			
	Verb, VP, S [1,2]	[1,3]			
		Det Det [2,3]			



**$\mathcal{L}_1$  Grammar**

$S \rightarrow NP VP$   
 $S \rightarrow X1 VP$   
 $X1 \rightarrow Aux NP$   
 $S \rightarrow book \mid include \mid prefer$   
 $S \rightarrow Verb NP$   
 $S \rightarrow X2 PP$   
 $S \rightarrow Verb PP$   
 $S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$   
 $NP \rightarrow TWA \mid Houston$   
 $NP \rightarrow Det Nominal$

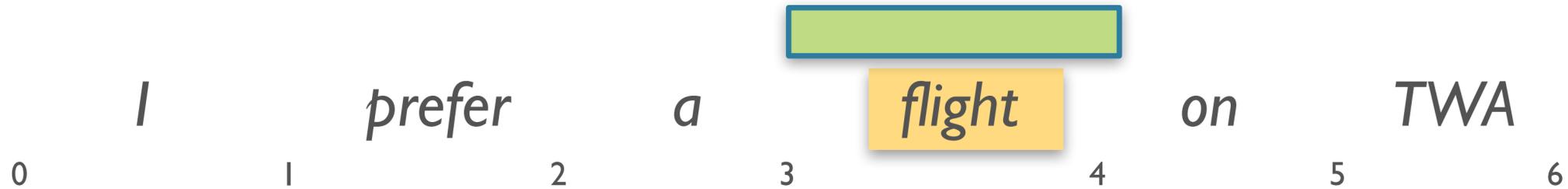
**Nominal**  $\rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$   
 $Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$   
 $VP \rightarrow Verb NP$   
 $VP \rightarrow X2 PP$   
 $X2 \rightarrow Verb NP$   
 $VP \rightarrow Verb PP$   
 $VP \rightarrow VP PP$   
 $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]			
	<b>Det</b> [2,3]				
			<b>Noun, Nom</b> [3,4]		

**Lexicon**

$Det \rightarrow that \mid this \mid a$   
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 $Aux \rightarrow does$   
 $Preposition \rightarrow from \mid to \mid on \mid near \mid through$   
 $Verb \rightarrow book \mid include \mid prefer$



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- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
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---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

---

- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]			
		<b>Det</b> [2,3]	[2,4]		
			<b>Noun, Nom</b> [3,4]		

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---

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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

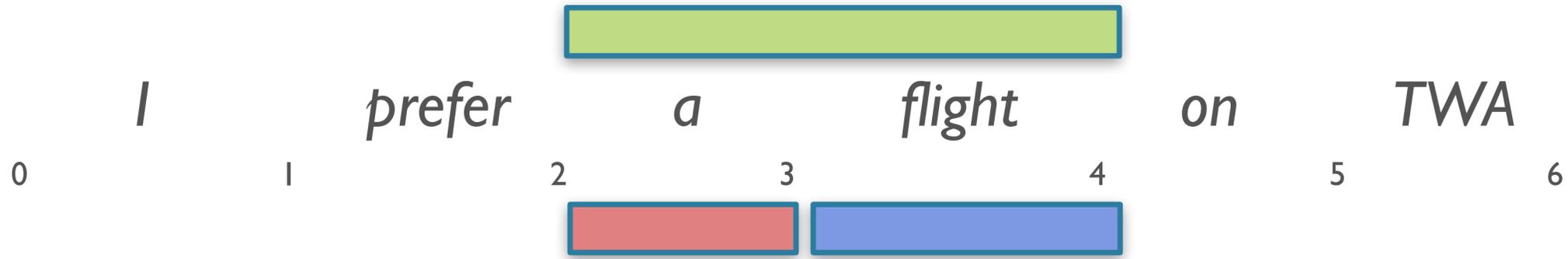
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]			
		<b>Det</b> [2,3]	[2,4]		
			<b>Noun, Nom</b> [3,4]		

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- $NP \rightarrow I \mid she \mid me$
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---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

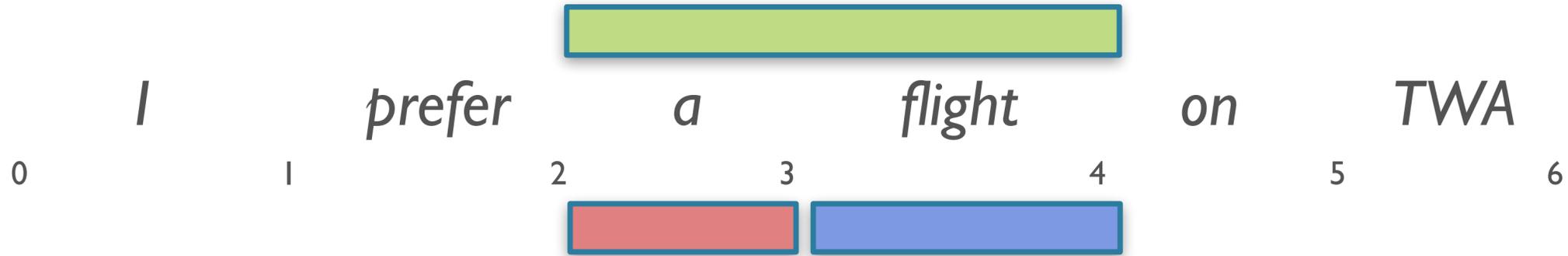
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun [0,1]</b>	<b>S [0,2]</b>	<b>[0,3]</b>			
	<b>Verb, VP, S [1,2]</b>	<b>[1,3]</b>			
		<b>Det [2,3]</b>	<b>NP [2,4]</b>		
			<b>Noun, Nom [3,4]</b>		

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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
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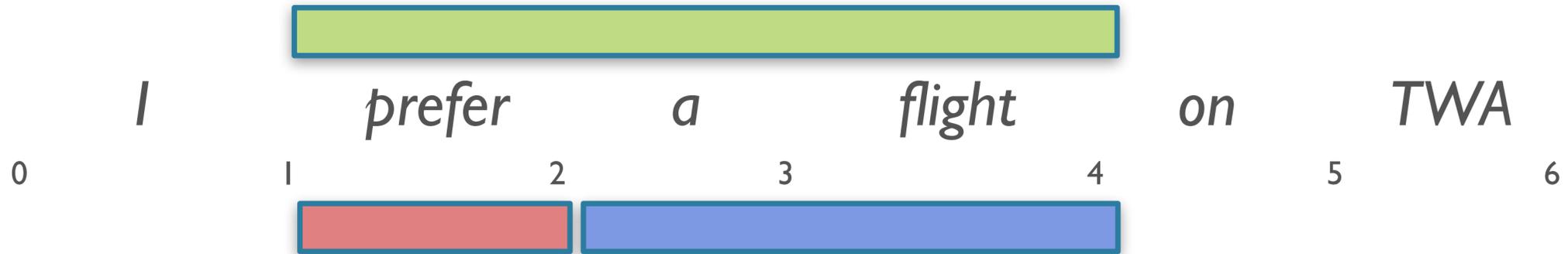
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>[1,4]</b>		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
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- $S \rightarrow book \mid include \mid prefer$
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- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

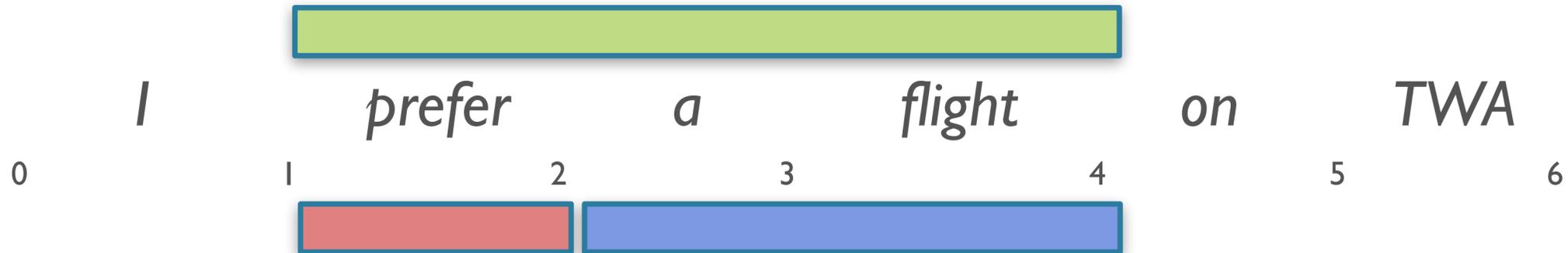
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- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $VP \rightarrow book \mid include \mid prefer$
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP</b> [1,4]		
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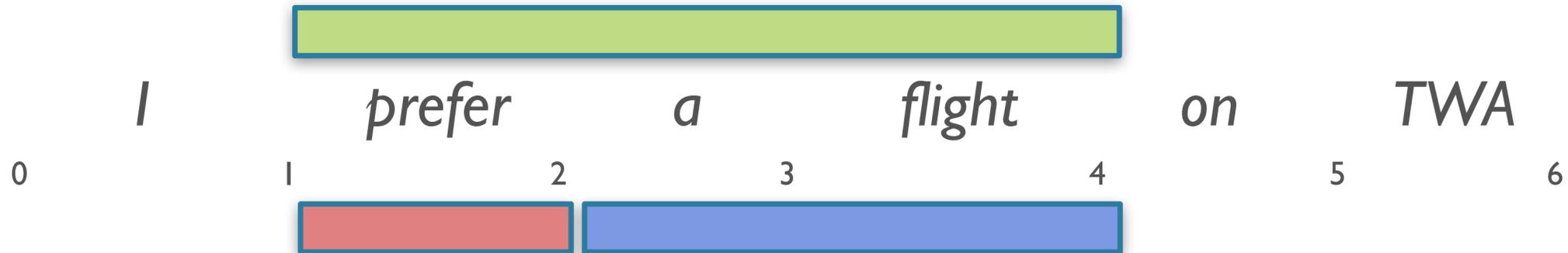
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]		

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- Aux*  $\rightarrow does$
- Preposition*  $\rightarrow from \mid to \mid on \mid near \mid through$
- Verb*  $\rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book / include / prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I / she / me$
- $NP \rightarrow TWA / Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book / flight / meal / money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book / include / prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
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- $VP \rightarrow VP PP$

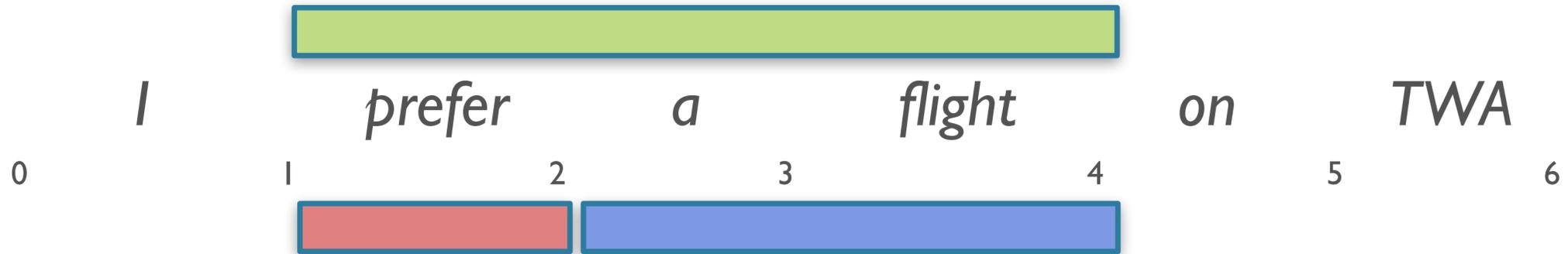
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]		

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- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
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- $S \rightarrow Verb PP$
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- $NP \rightarrow TWA \mid Houston$
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- $Nominal \rightarrow Nominal PP$

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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

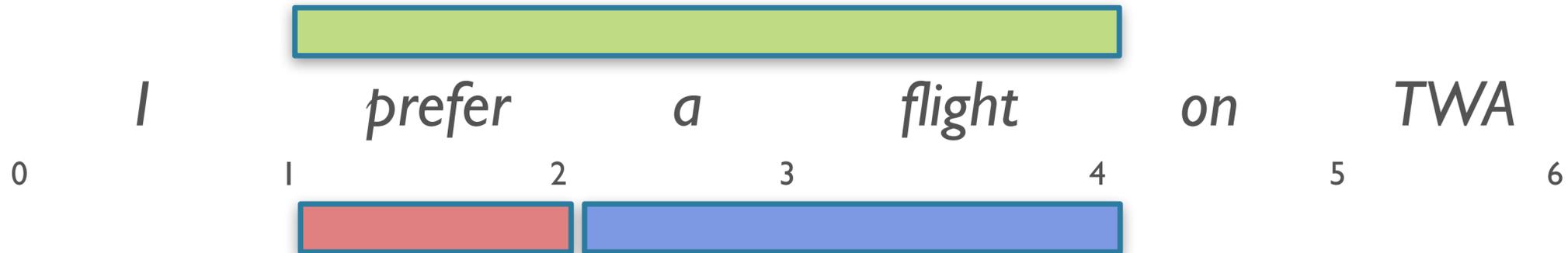
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]		

**Lexicon**

- Det*  $\rightarrow that \mid this \mid a$
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- Aux*  $\rightarrow does$
- Preposition*  $\rightarrow from \mid to \mid on \mid near \mid through$
- Verb*  $\rightarrow book \mid include \mid prefer$



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- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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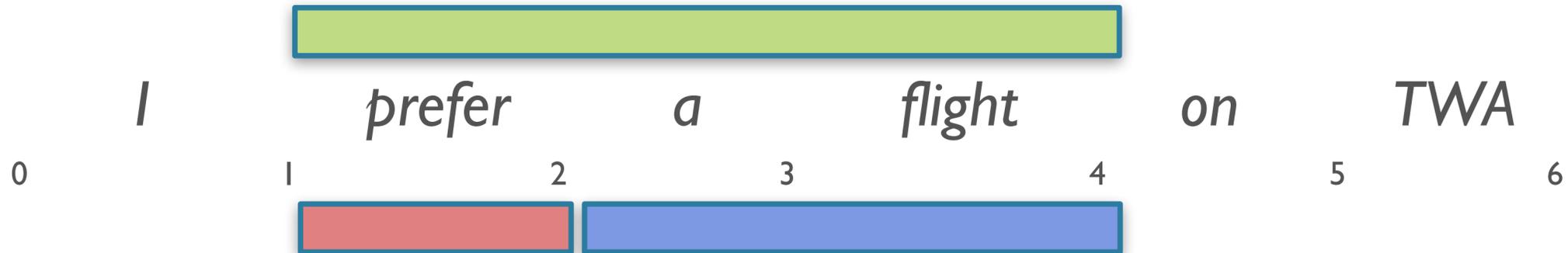
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]		

**Lexicon**

- Det*  $\rightarrow that \mid this \mid a$
- Noun*  $\rightarrow book \mid flight \mid meal \mid money$
- Pronoun*  $\rightarrow I \mid she \mid me$
- Proper-Noun*  $\rightarrow Houston \mid TWA$
- Aux*  $\rightarrow does$
- Preposition*  $\rightarrow from \mid to \mid on \mid near \mid through$
- Verb*  $\rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

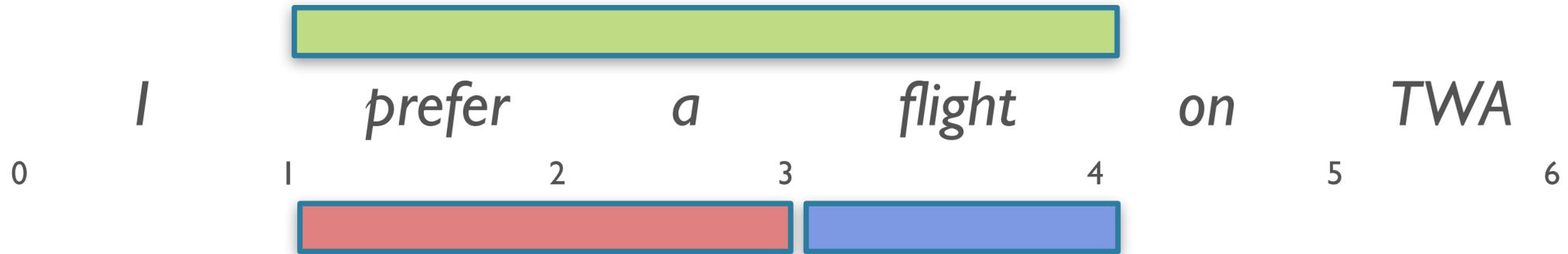
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun [0,1]</b>	<b>S [0,2]</b>	<b>[0,3]</b>			
	<b>Verb, VP, S [1,2]</b>	<b>[1,3]</b>	<b>VP, X2, S [1,4]</b>		
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- $VP \rightarrow book \mid include \mid prefer$
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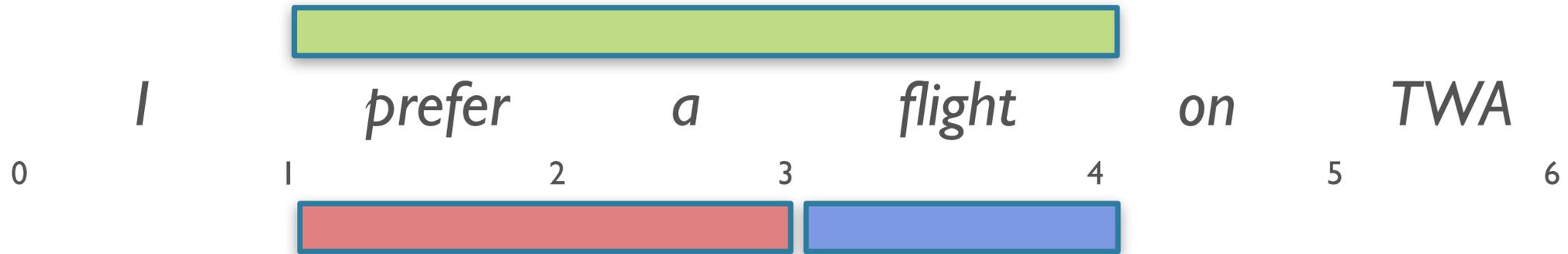
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]			
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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $VP \rightarrow Verb PP$
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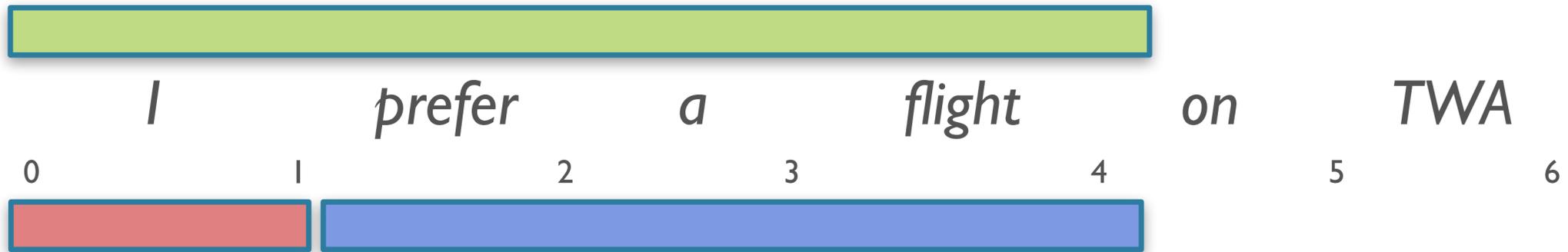
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	[0,4]		
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

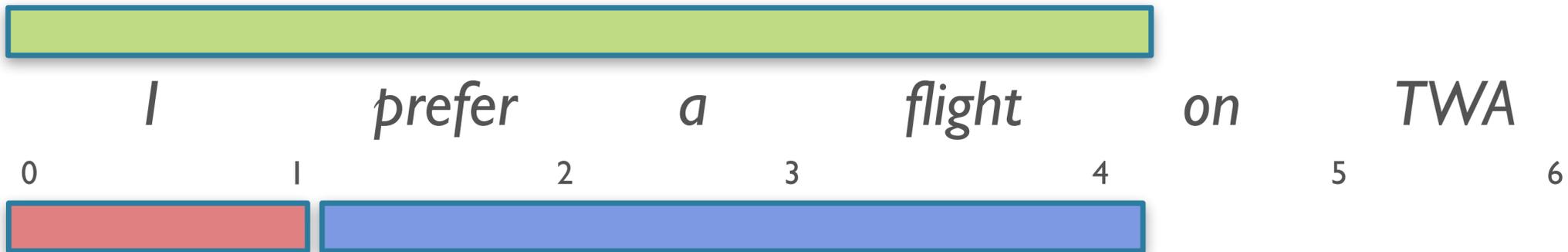
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
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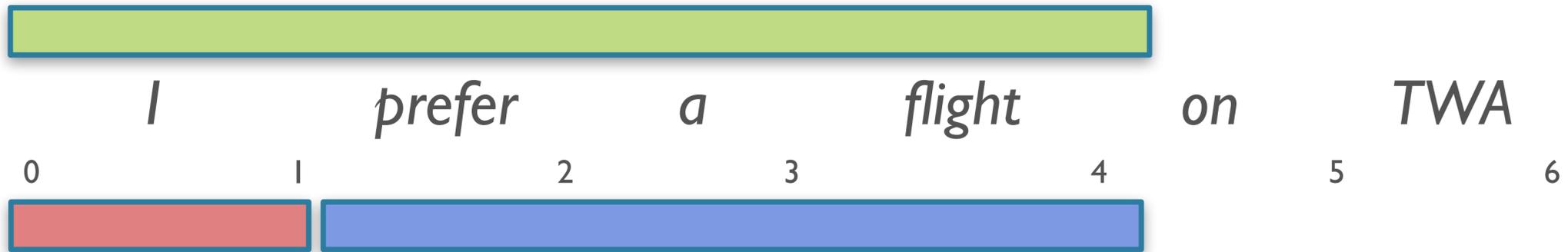
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
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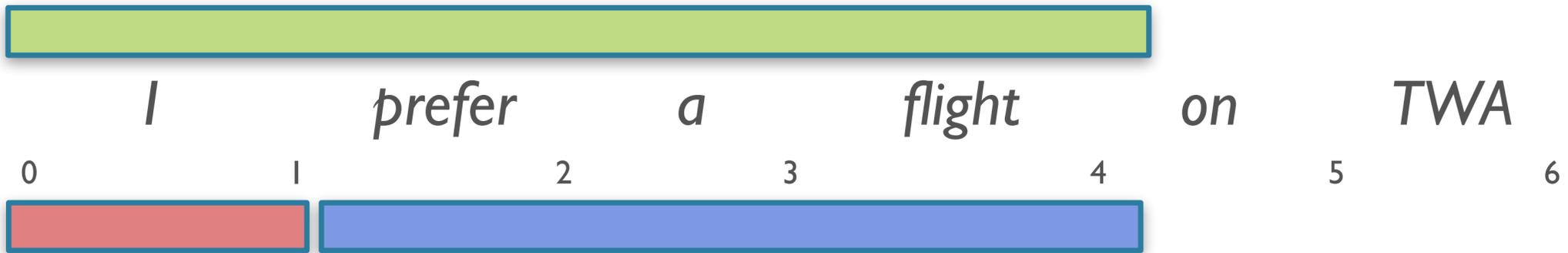
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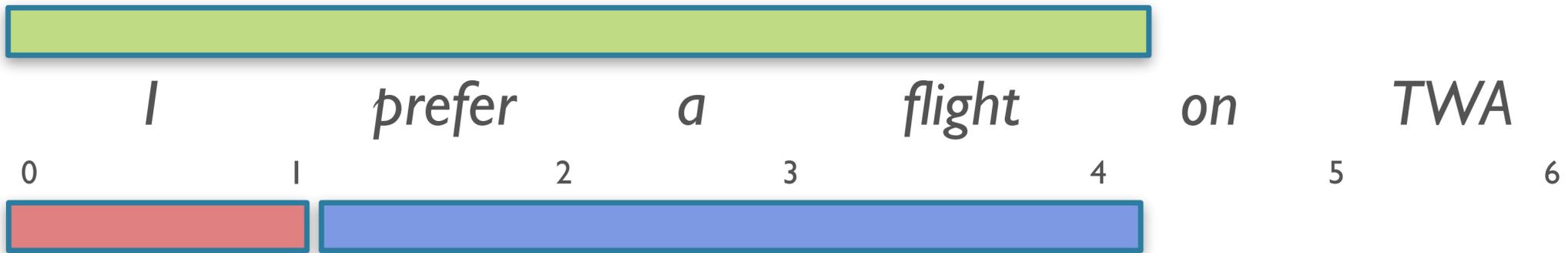
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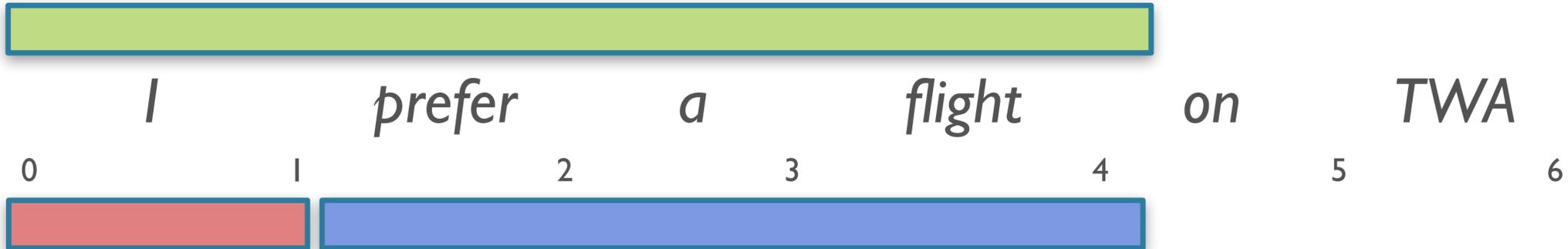
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
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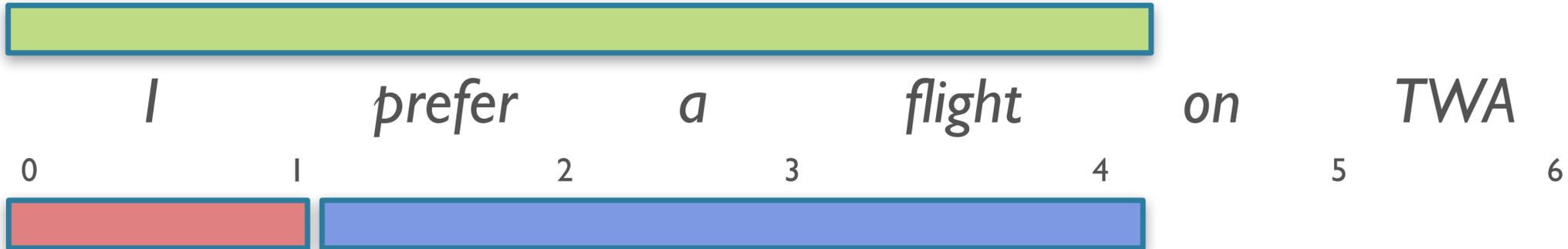
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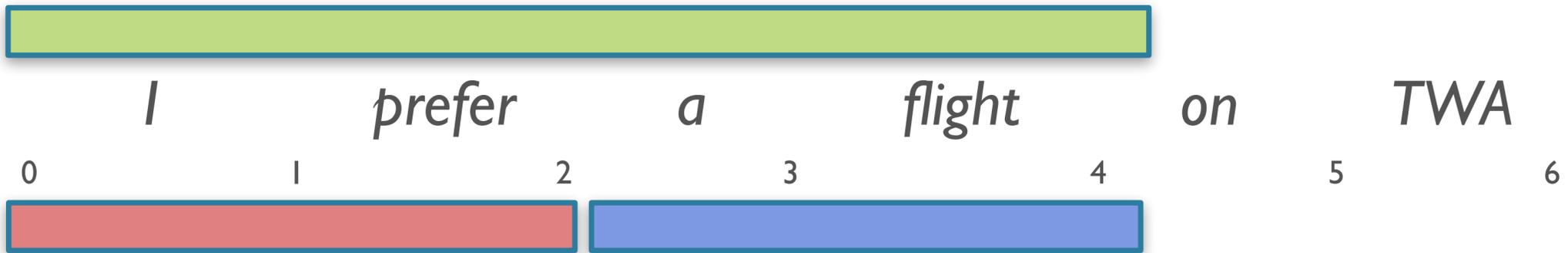
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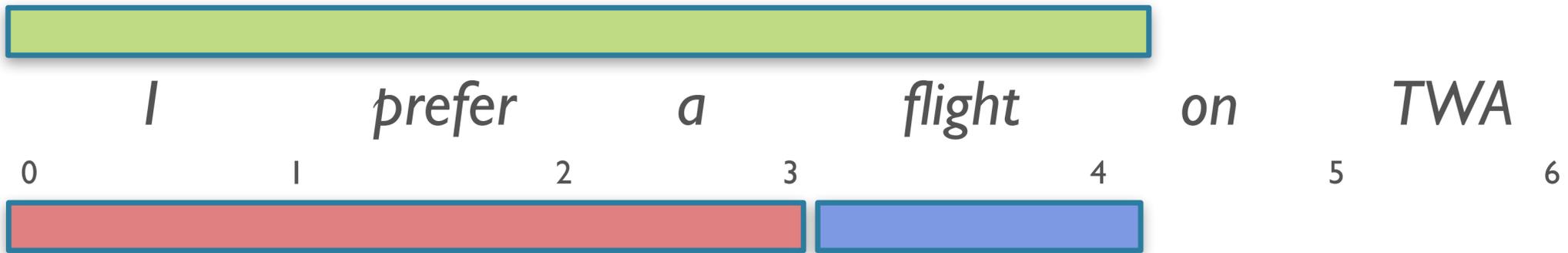
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	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]		
				<b>Prep</b> [4,5]	

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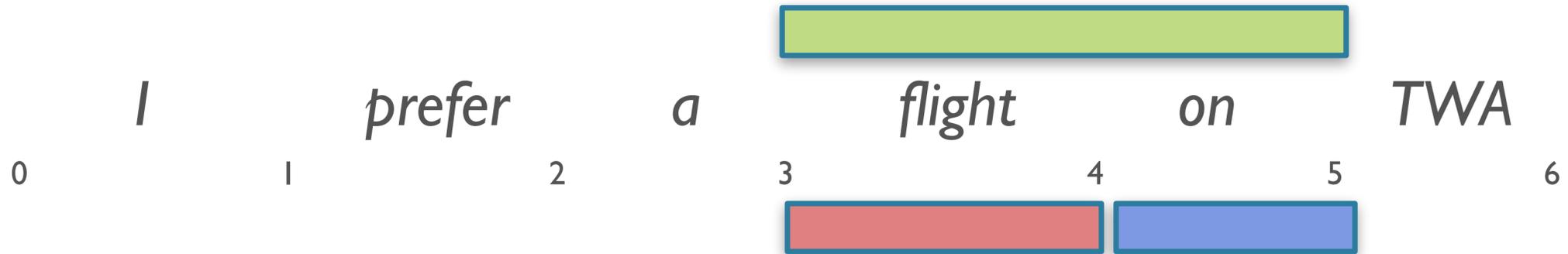
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		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

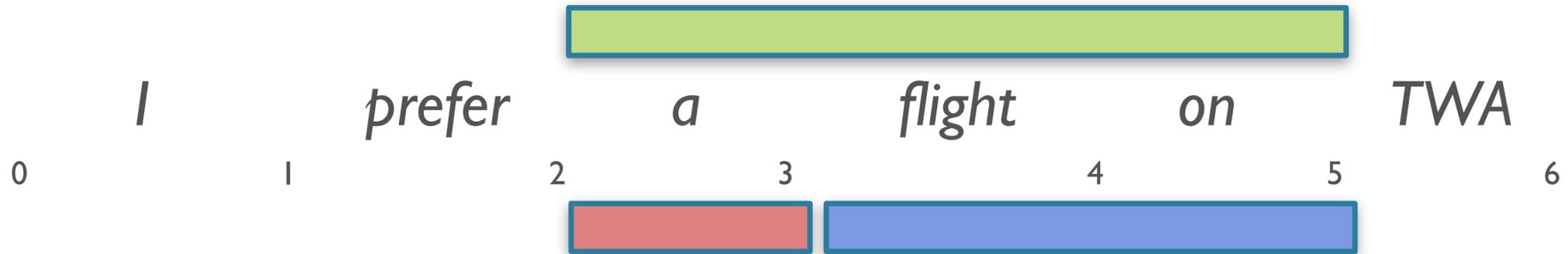
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun [0,1]</b>	<b>S [0,2]</b>	<b>[0,3]</b>	<b>S [0,4]</b>		
	<b>Verb, VP, S [1,2]</b>	<b>[1,3]</b>	<b>VP, X2, S [1,4]</b>		
		<b>Det [2,3]</b>	<b>NP [2,4]</b>	<b>[2,5]</b>	
			<b>Noun, Nom [3,4]</b>	<b>[3,5]</b>	
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- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

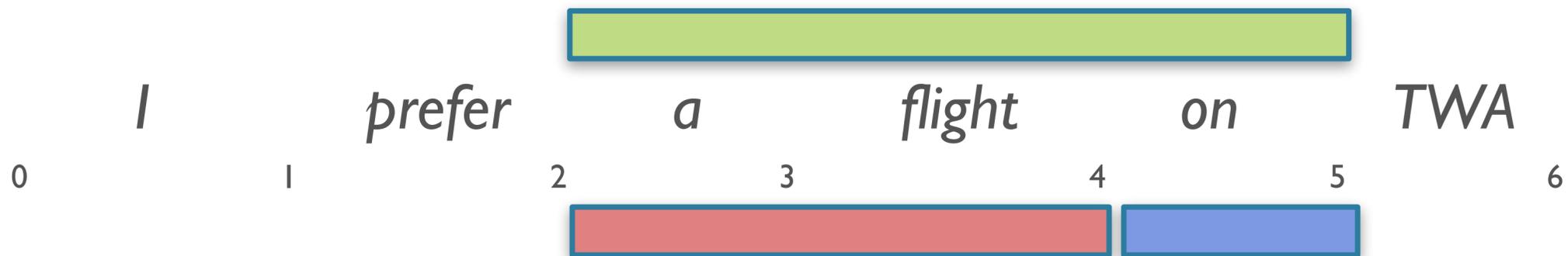
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
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- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

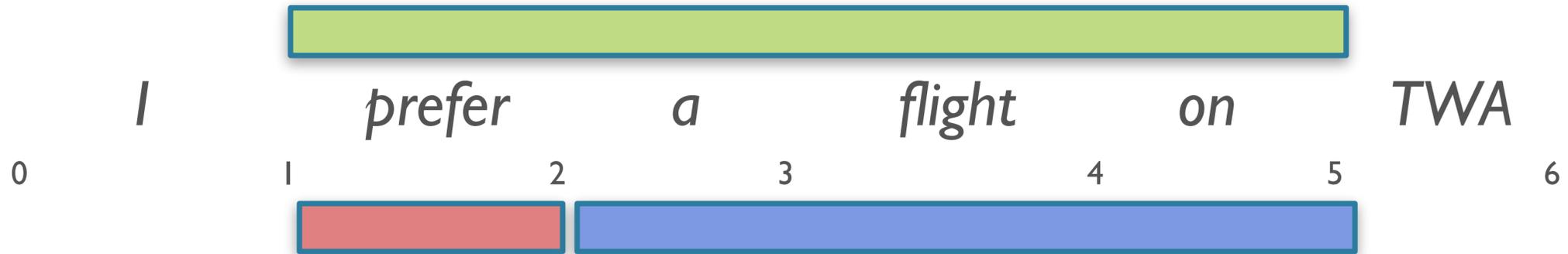
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
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- $NP \rightarrow Det Nominal$

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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

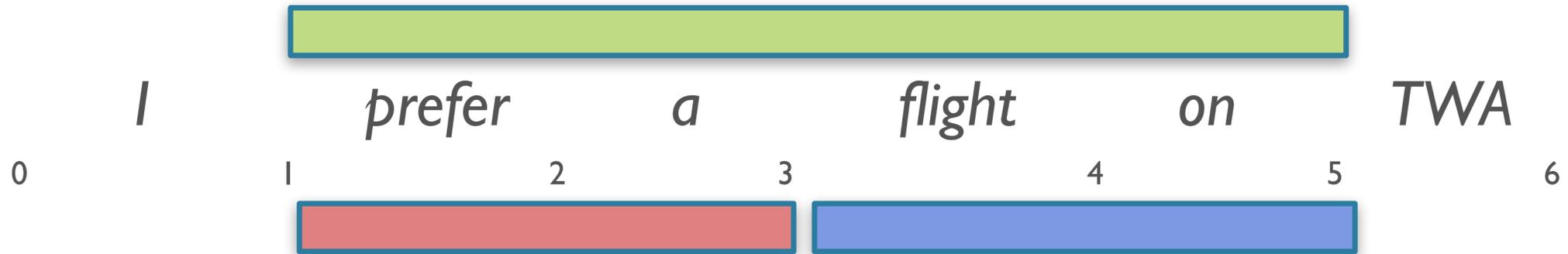
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
	<b>Verb, VP, S</b> [1,2]	<b>[1,3]</b>	<b>VP, X2, S</b> [1,4]	<b>[1,5]</b>	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	<b>[3,5]</b>	
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- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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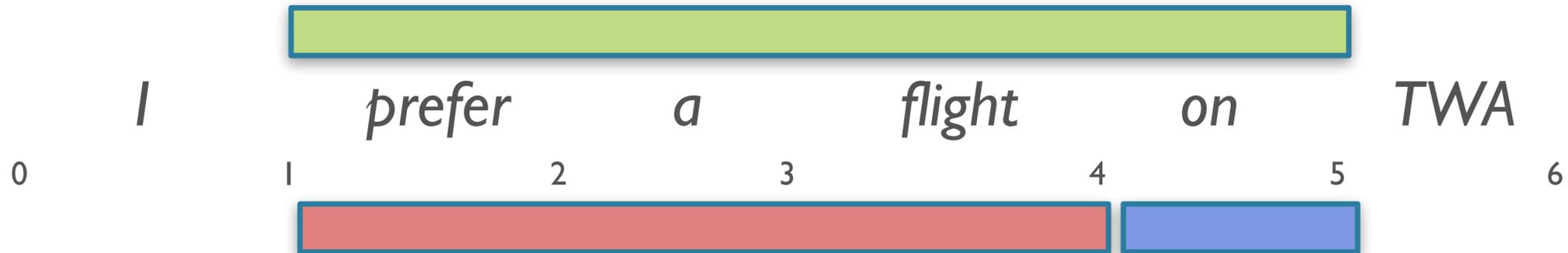
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$
- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]		
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
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- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
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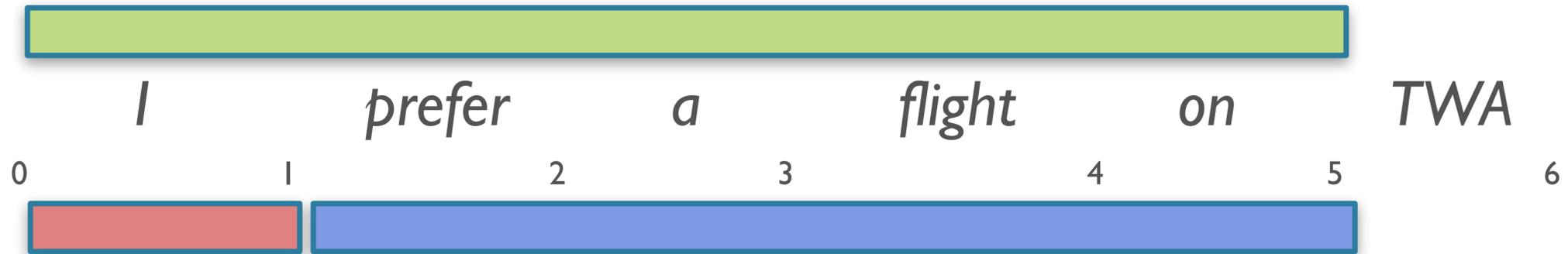
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
	<b>Det</b> [2,3]	[2,4]	<b>NP</b> [2,4]	[2,5]	
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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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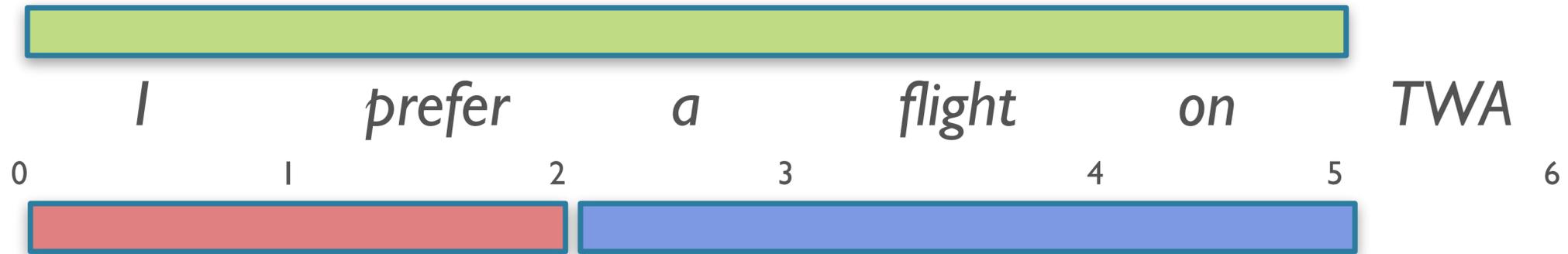
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	<b>[0,3]</b>	<b>S</b> [0,4]	<b>[0,5]</b>	
	<b>Verb, VP, S</b> [1,2]		<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		
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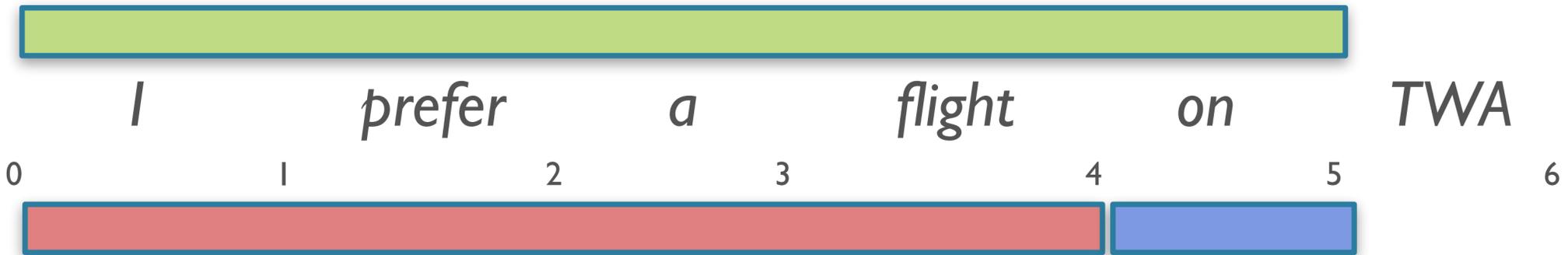
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	<b>S</b> [0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
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		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
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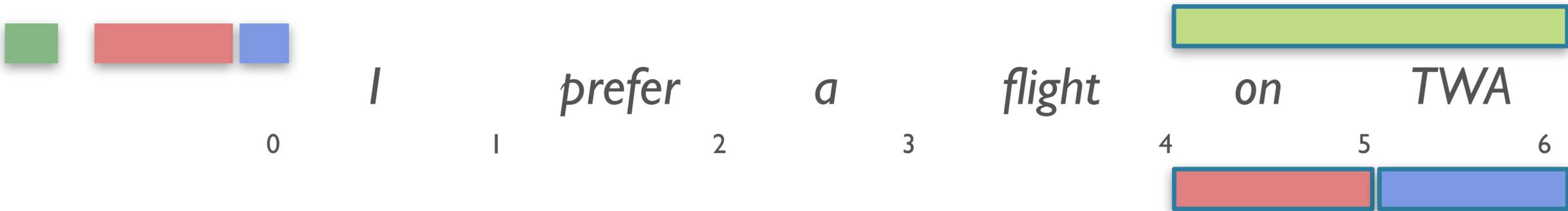
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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 $X1 \rightarrow Aux NP$   
 $S \rightarrow book \mid include \mid prefer$   
 $S \rightarrow Verb NP$   
 $S \rightarrow X2 PP$   
 $S \rightarrow Verb PP$   
 $S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$   
 $NP \rightarrow TWA \mid Houston$   
 $NP \rightarrow Det Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$   
 $Nominal \rightarrow Nominal Noun$

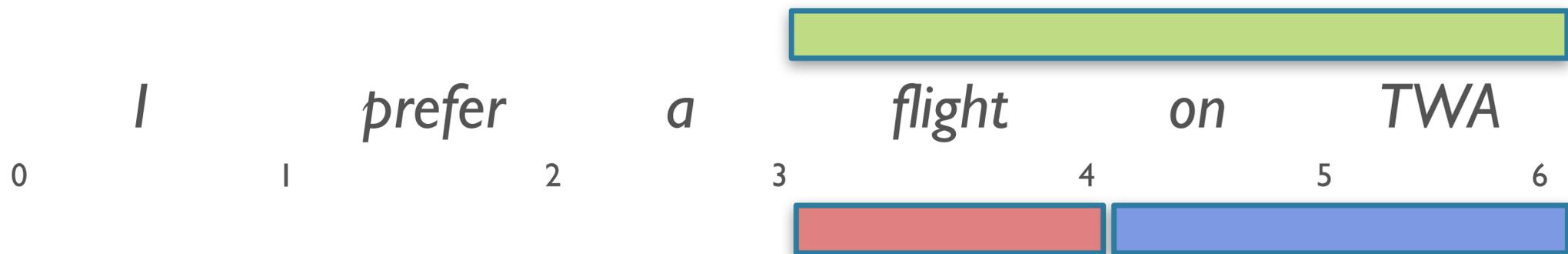
$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$   
 $VP \rightarrow Verb NP$   
 $VP \rightarrow X2 PP$   
 $X2 \rightarrow Verb NP$   
 $VP \rightarrow Verb PP$   
 $VP \rightarrow VP PP$   
 $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

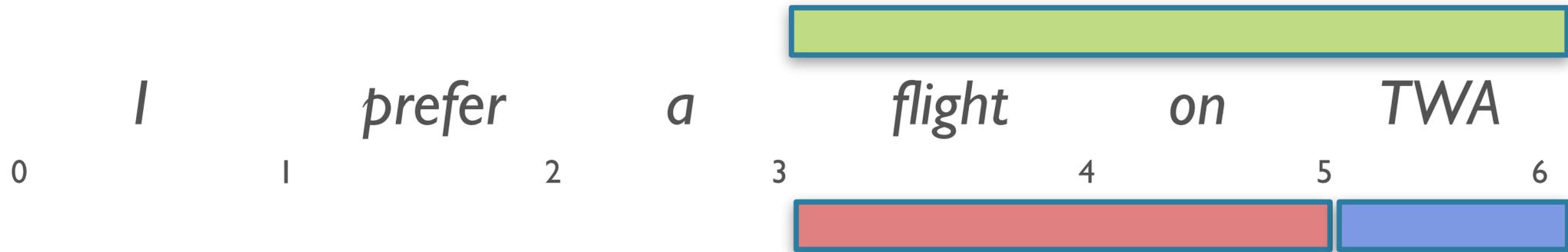
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	
			<b>Noun, Nom</b> [3,4]	<b>[3,5]</b>	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
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- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

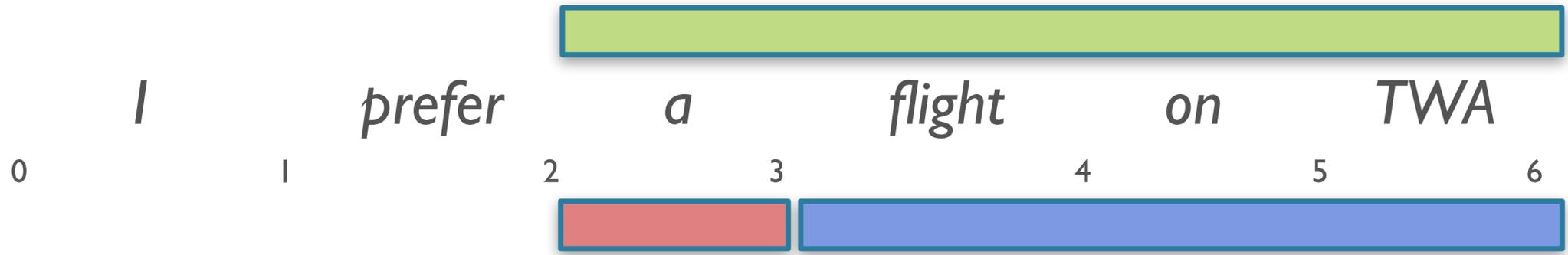
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

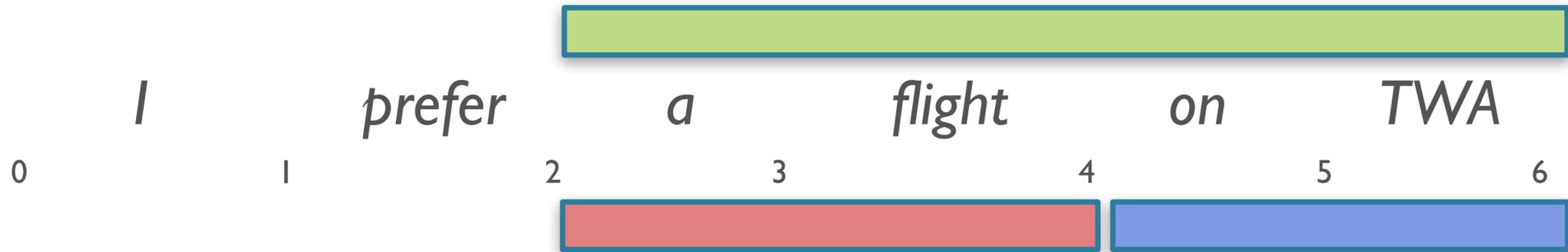
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

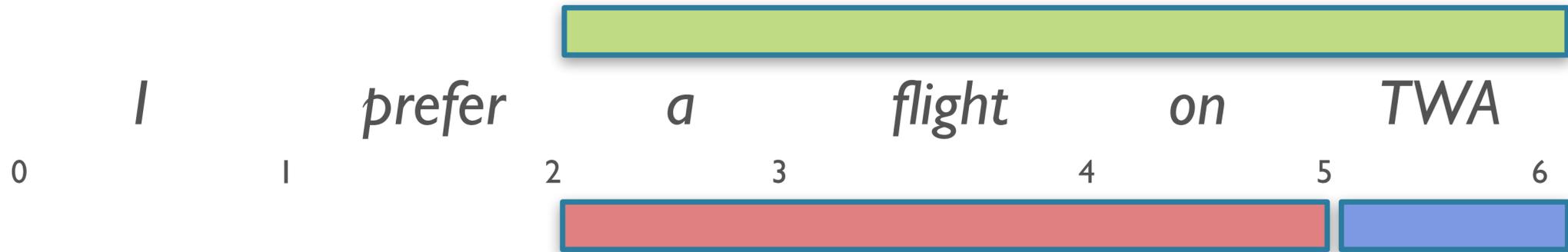
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	<b>[2,5]</b>	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
- Pronoun* → I | she | me
- Proper-Noun* → Houston | TWA
- Aux* → does
- Preposition* → from | to | on | near | through
- Verb* → book | include | prefer



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

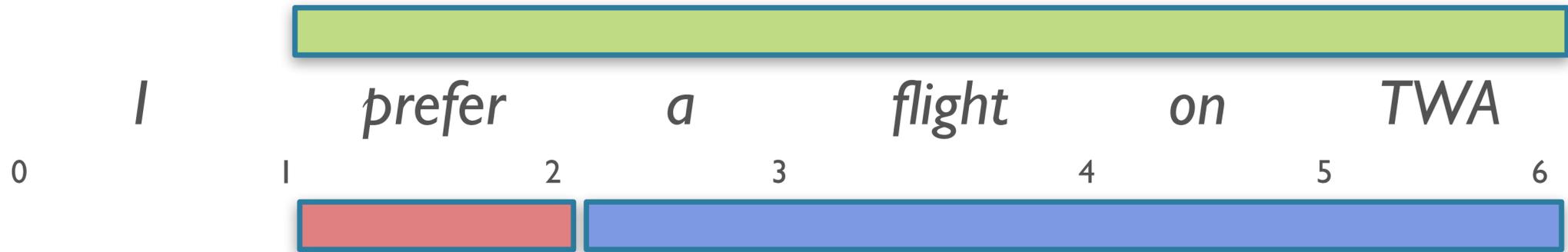
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]		<b>VP, X2, S</b> [1,4]		
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]		<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
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- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
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- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

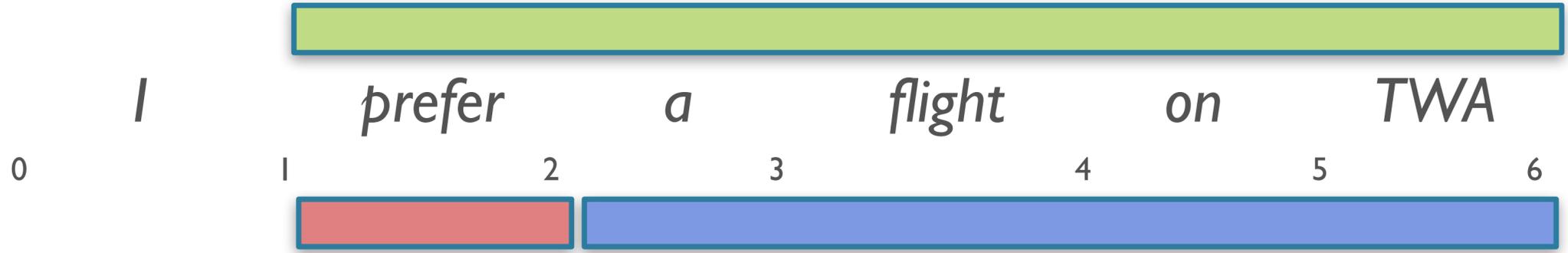
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]		<b>VP, X2, S</b> [1,4]		<b>VP</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]		<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

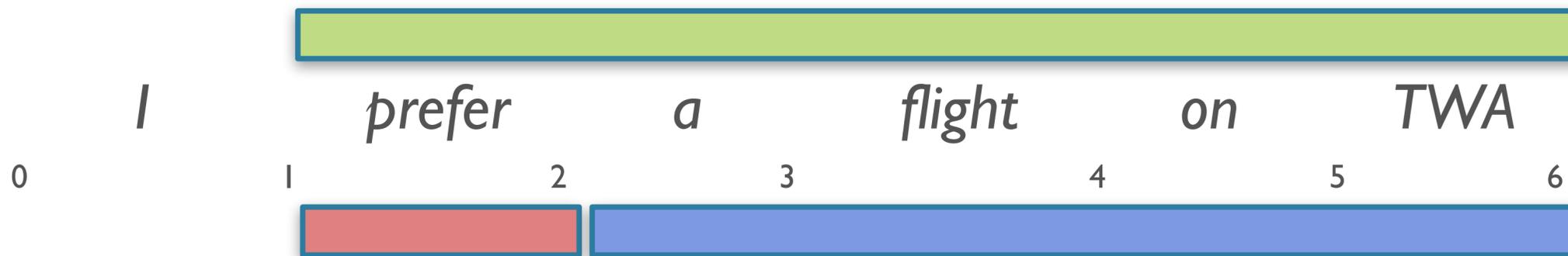
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

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**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
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- $S \rightarrow X2 PP$
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- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

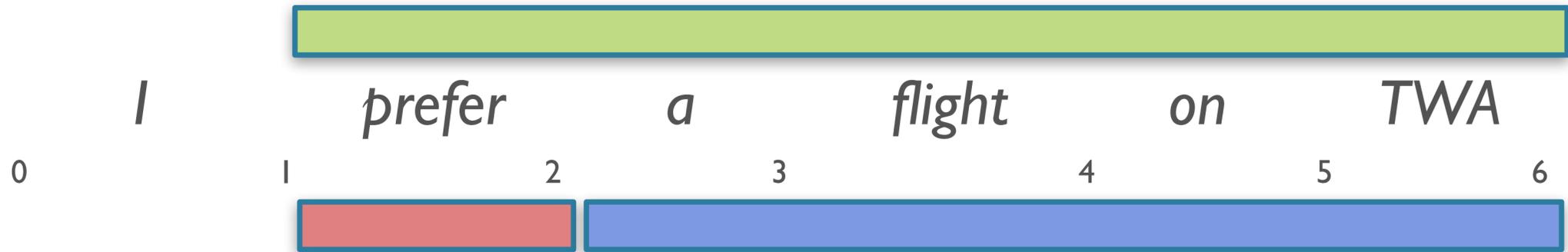
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]		<b>VP, X2, S</b> [1,4]		<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]		<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

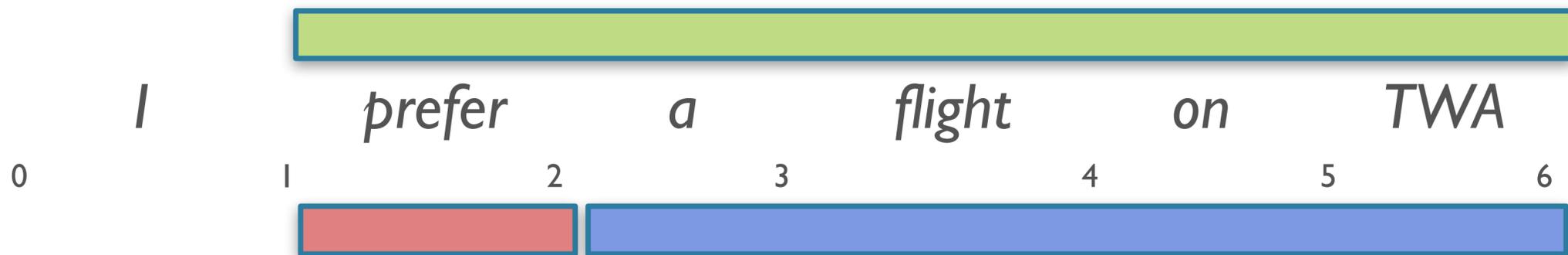
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]		<b>VP, X2, S</b> [1,4]		<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]		<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]		<b>Nom</b> [3,6]
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					<b>NNP, NP</b> [5,6]

**Lexicon**

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- $VP \rightarrow Verb NP$
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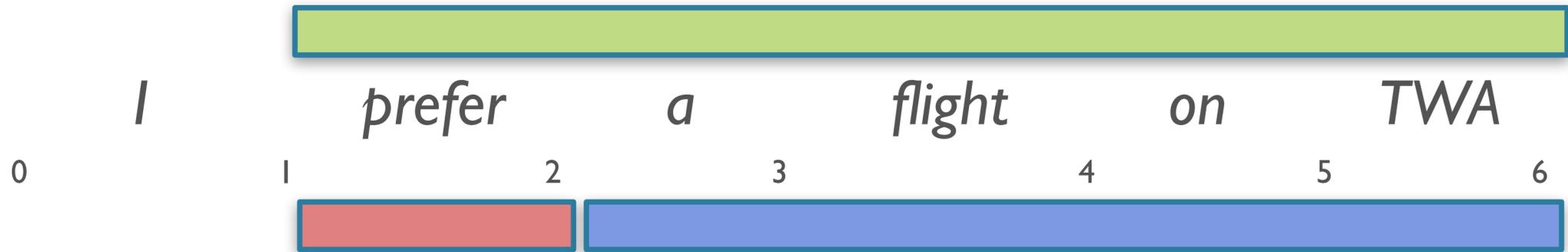
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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- $X2 \rightarrow Verb NP$
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- $VP \rightarrow VP PP$

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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	<b>[1,3]</b>	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

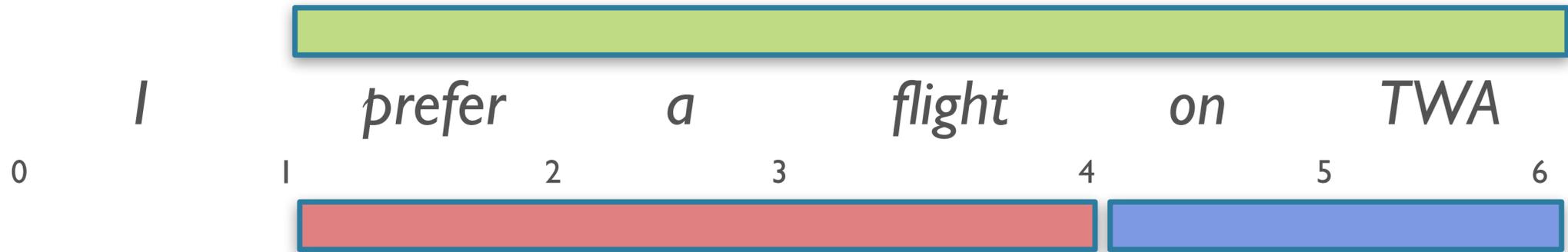
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

**Lexicon**

- $Det \rightarrow that \mid this \mid a$
- $Noun \rightarrow book \mid flight \mid meal \mid money$
- $Pronoun \rightarrow I \mid she \mid me$
- $Proper-Noun \rightarrow Houston \mid TWA$
- $Aux \rightarrow does$
- $Preposition \rightarrow from \mid to \mid on \mid near \mid through$
- $Verb \rightarrow book \mid include \mid prefer$



**$\mathcal{L}_1$  Grammar**

- $S \rightarrow NP VP$
- $S \rightarrow X1 VP$
- $X1 \rightarrow Aux NP$
- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

---

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
- $Nominal \rightarrow Nominal Noun$
- $Nominal \rightarrow Nominal PP$

---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

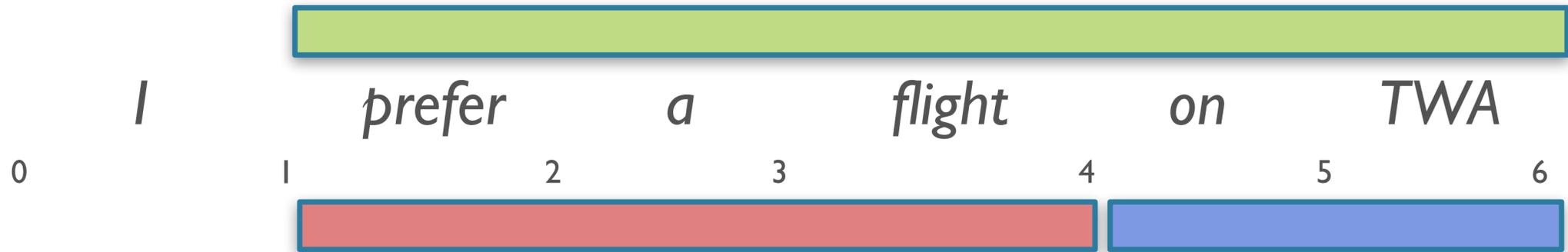
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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**Lexicon**

- Det* → that | this | a
- Noun* → book | flight | meal | money
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- $S \rightarrow book \mid include \mid prefer$
- $S \rightarrow Verb NP$
- $S \rightarrow X2 PP$
- $S \rightarrow Verb PP$
- $S \rightarrow VP PP$

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- $NP \rightarrow I \mid she \mid me$
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- $NP \rightarrow Det Nominal$

---

- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
- $VP \rightarrow X2 PP$
- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

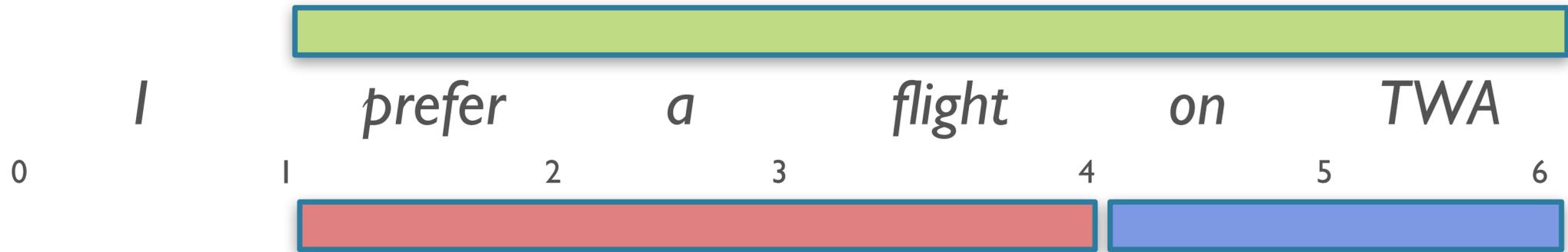
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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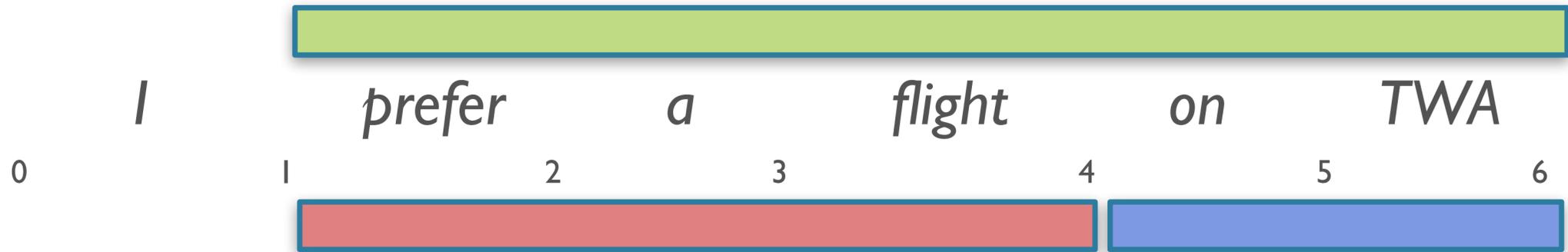
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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- $S \rightarrow VP PP$

---

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---

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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

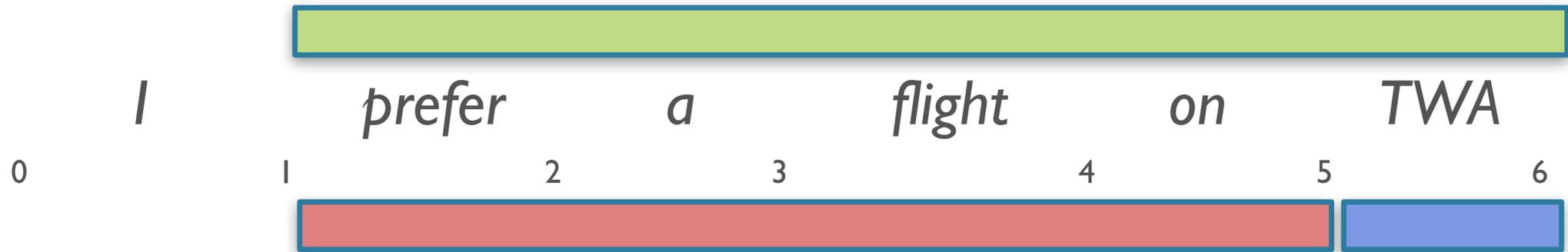
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	<b>[1,5]</b>	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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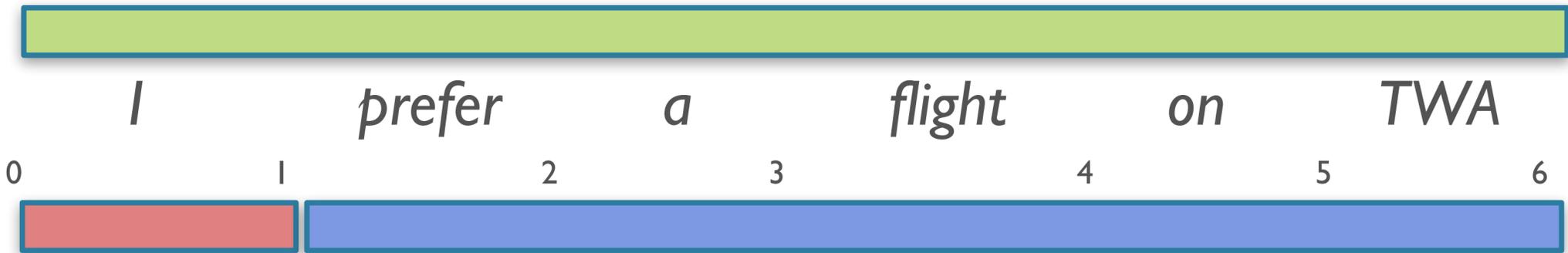
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	[0,6]
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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---

- $VP \rightarrow book \mid include \mid prefer$
- $VP \rightarrow Verb NP$
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- $X2 \rightarrow Verb NP$
- $VP \rightarrow Verb PP$
- $VP \rightarrow VP PP$

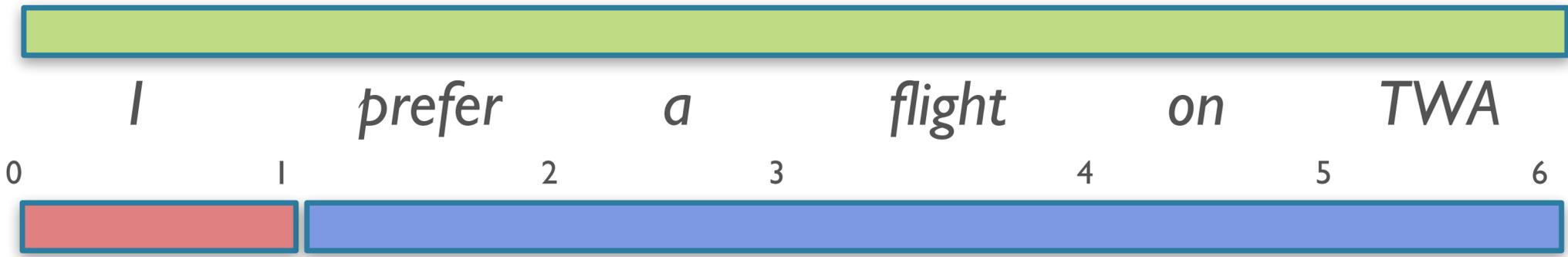
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	<b>S</b> [0,6]
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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- $S \rightarrow VP PP$

- $NP \rightarrow I \mid she \mid me$
- $NP \rightarrow TWA \mid Houston$
- $NP \rightarrow Det Nominal$

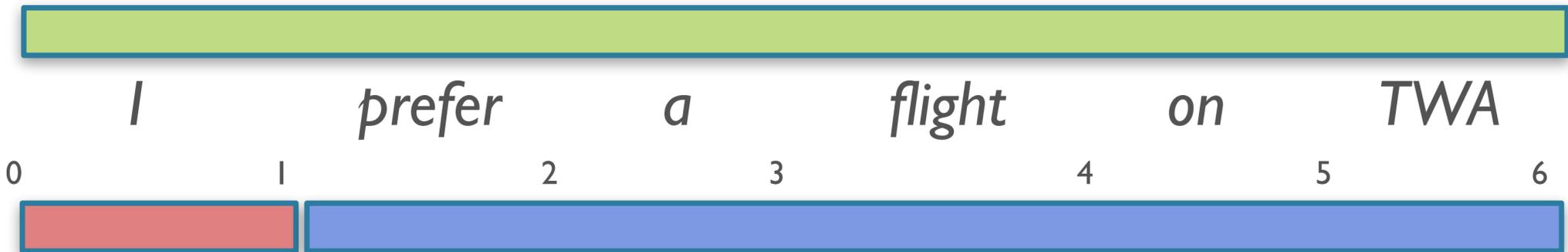
- $Nominal \rightarrow book \mid flight \mid meal \mid money$
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	<b>S</b> [0,6]
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		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
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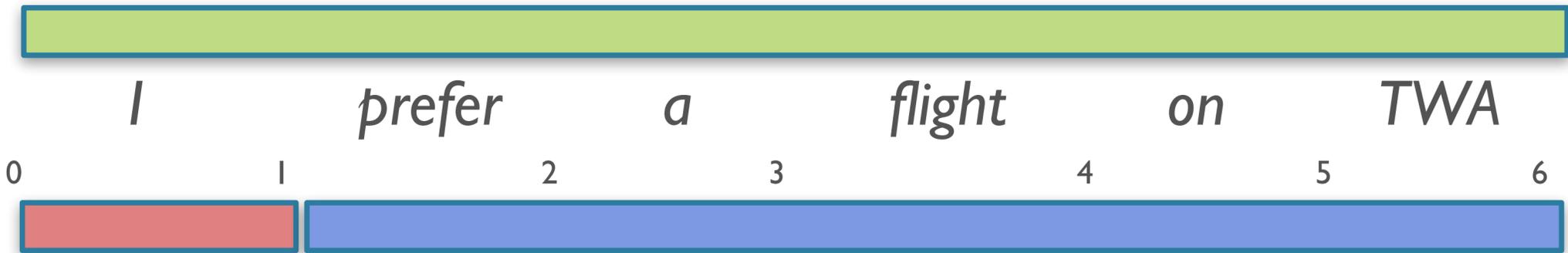
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	<b>[0,3]</b>	<b>S</b> [0,4]	<b>[0,5]</b>	<b>S</b> [0,6]
	<b>Verb, VP, S</b> [1,2]	<b>[1,3]</b>	<b>VP, X2, S</b> [1,4]	<b>[1,5]</b>	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	<b>[2,5]</b>	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	<b>[3,5]</b>	<b>Nom</b> [3,6]
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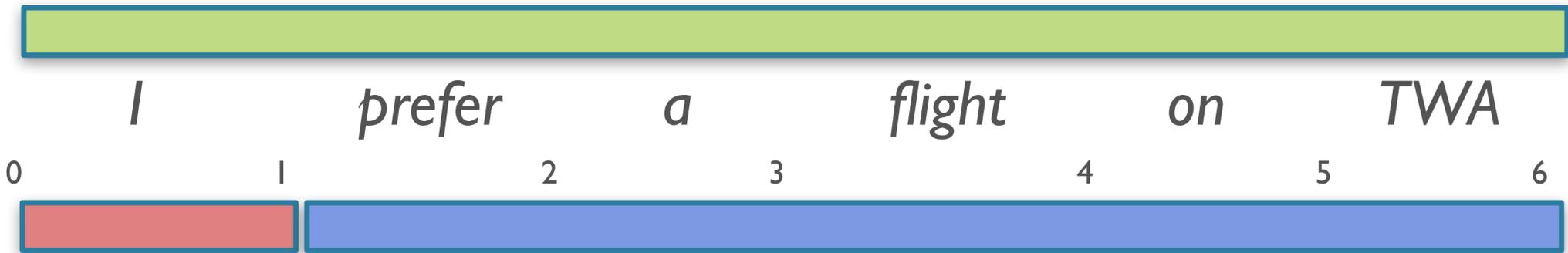
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- $PP \rightarrow Preposition NP$

<b>NP, Pronoun [0,1]</b>	<b>S [0,2]</b>	<b>[0,3]</b>	<b>S [0,4]</b>	<b>[0,5]</b>	<b>S [0,6]</b>
	<b>Verb, VP, S [1,2]</b>	<b>[1,3]</b>	<b>VP, X2, S [1,4]</b>	<b>[1,5]</b>	<b>VP, X2, S [1,6]</b>
		<b>Det [2,3]</b>	<b>NP [2,4]</b>	<b>[2,5]</b>	<b>NP [2,6]</b>
			<b>Noun, Nom [3,4]</b>	<b>[3,5]</b>	<b>Nom [3,6]</b>
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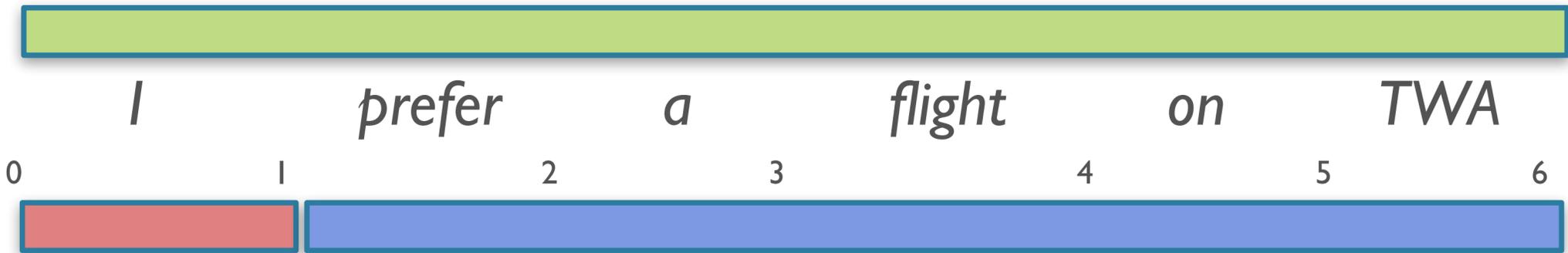
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<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	<b>S</b> [0,6]
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP, X2, S</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
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# Current CKY Algorithm

Limitations:

Only stores non-terminals in cell

Not rules or cells corresponding to RHS

Stores SETS of non-terminals

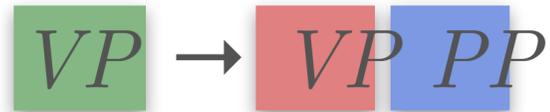
Multiple rules with same LHS collide

Currently only *acceptance/recognition*

# CKY *Parser*

- Pair each nonterminal with back-pointer to cells from which it was derived
- Last step:
  - construct trees from back-pointers in  $[ 0, n ]$

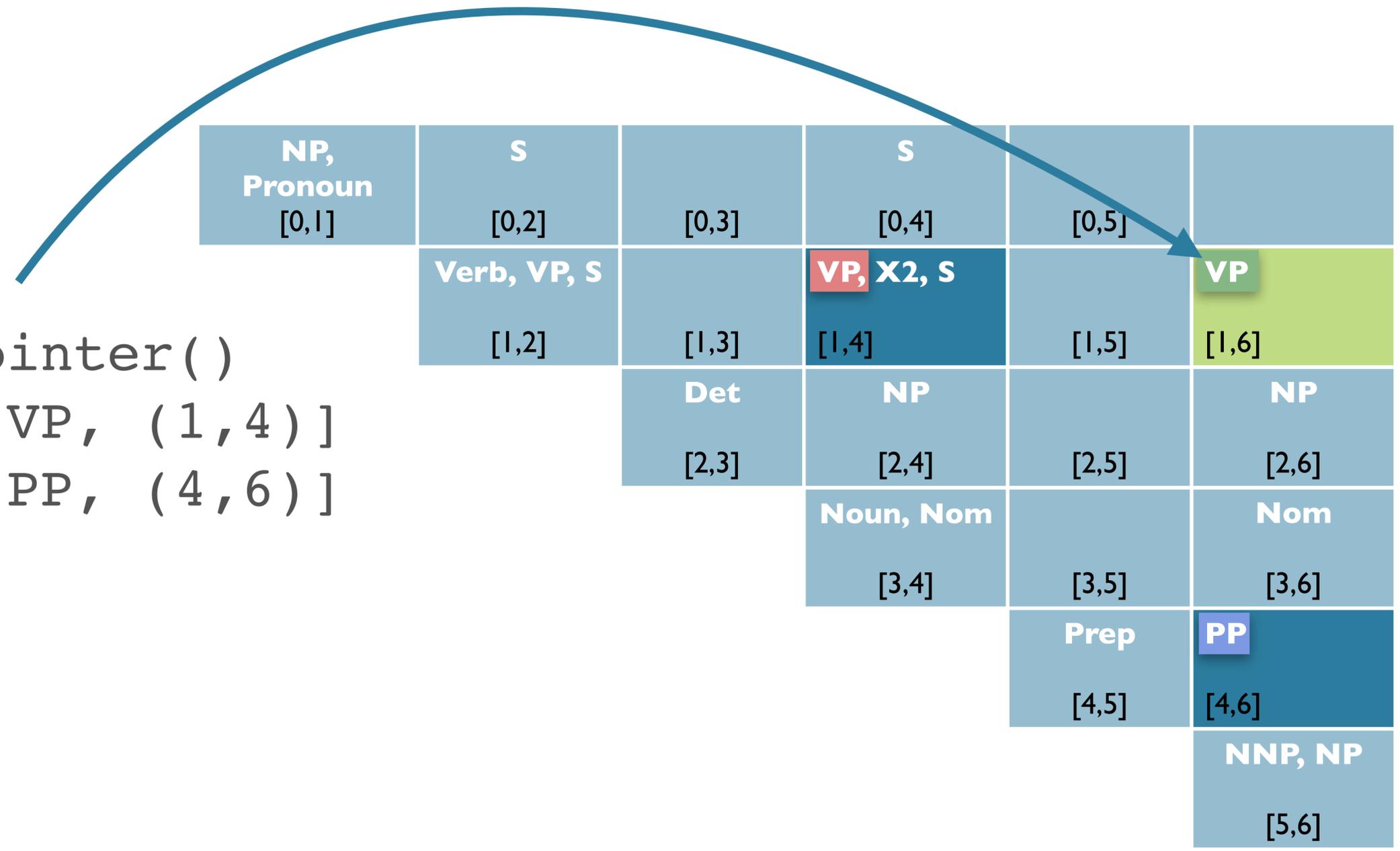
<b>NP, Pronoun</b> [0,1]	<b>S</b> [0,2]	[0,3]	<b>S</b> [0,4]	[0,5]	
	<b>Verb, VP, S</b> [1,2]	[1,3]	<b>VP, X2, S</b> [1,4]	[1,5]	<b>VP</b> [1,6]
		<b>Det</b> [2,3]	<b>NP</b> [2,4]	[2,5]	<b>NP</b> [2,6]
			<b>Noun, Nom</b> [3,4]	[3,5]	<b>Nom</b> [3,6]
				<b>Prep</b> [4,5]	<b>PP</b> [4,6]
					<b>NNP, NP</b> [5,6]

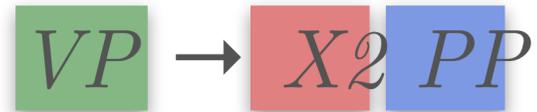


```

bp_1 = BackPointer()
bp_1.l_child = [VP, (1,4)]
bp_1.r_child = [PP, (4,6)]

```

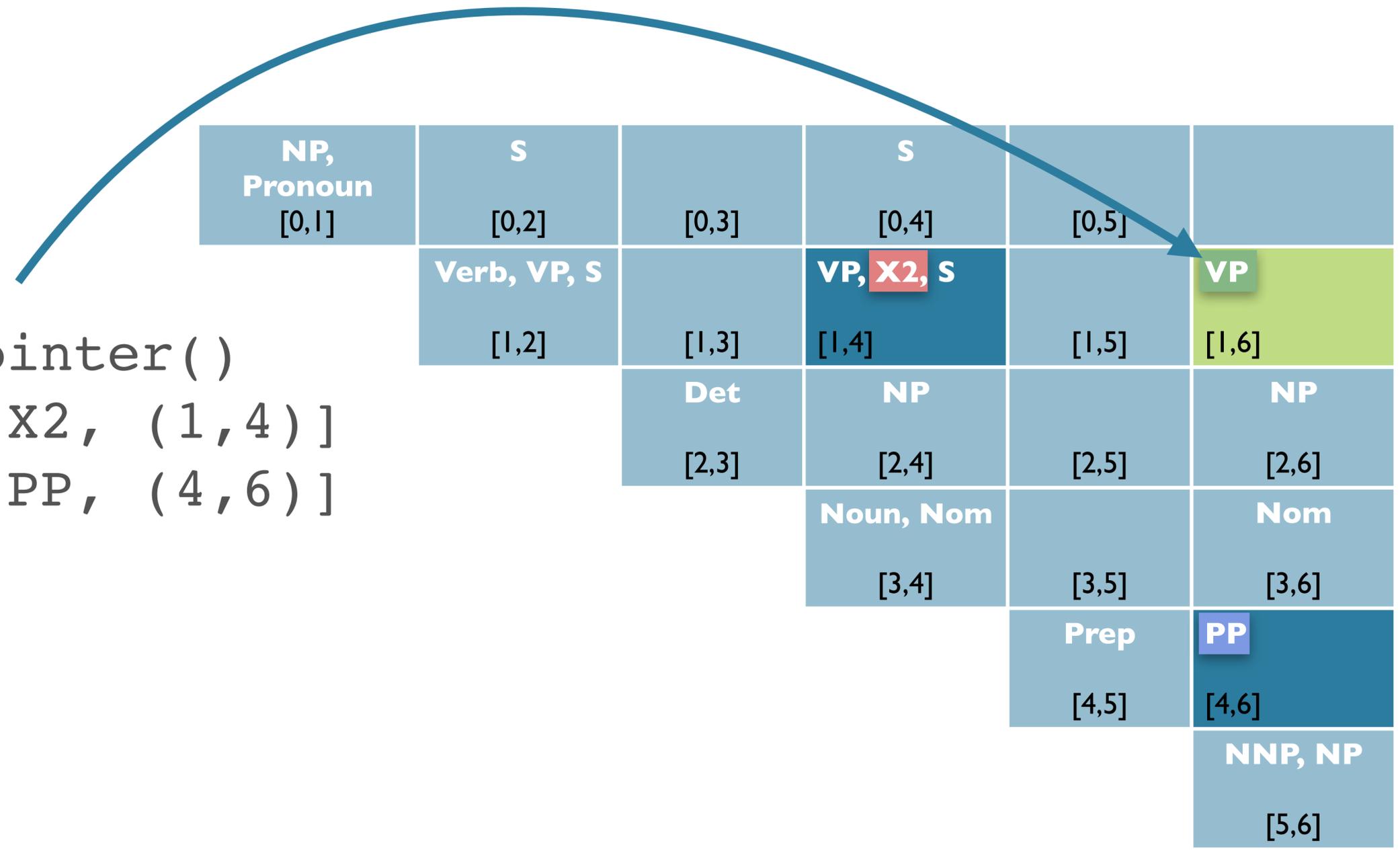




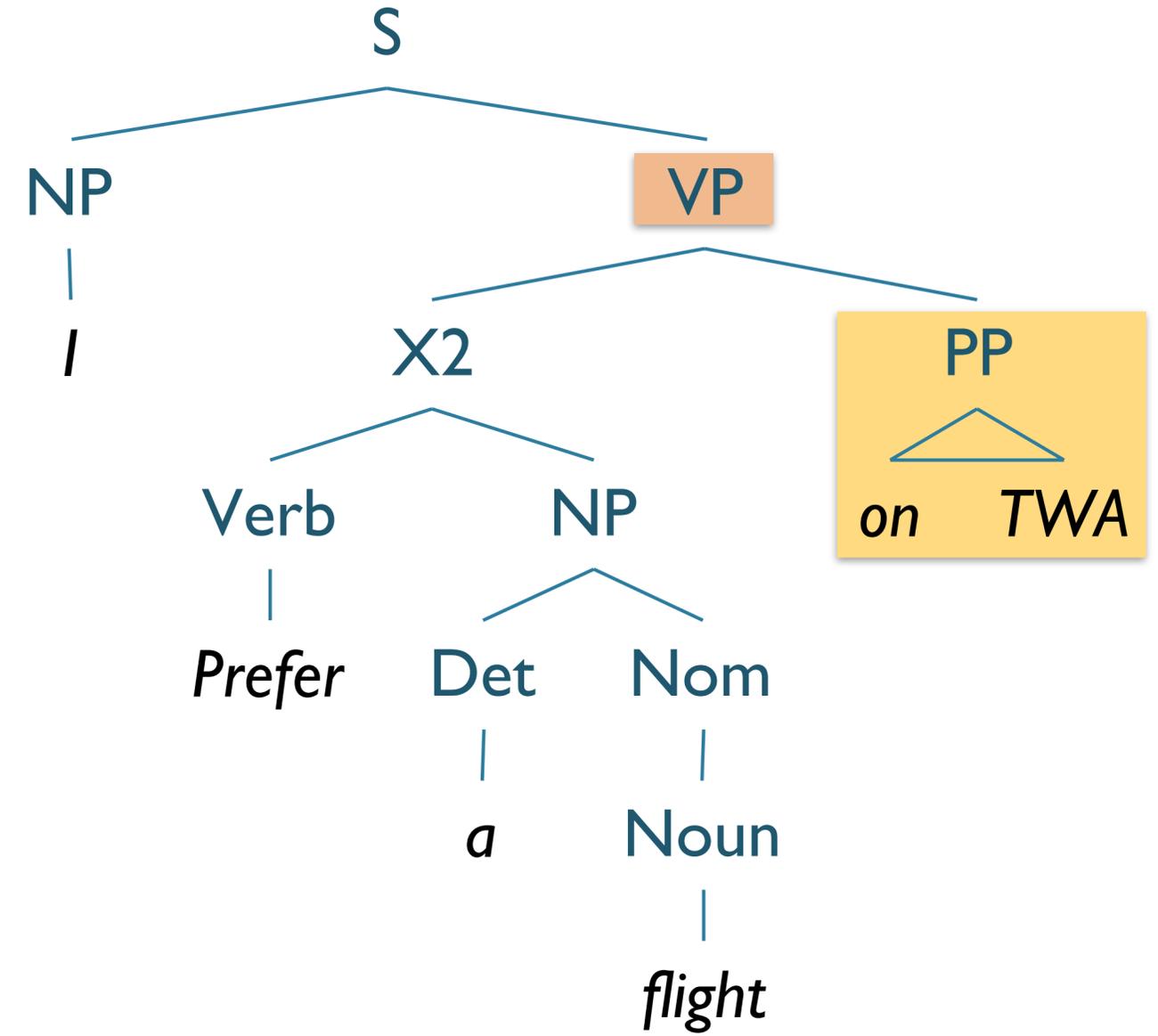
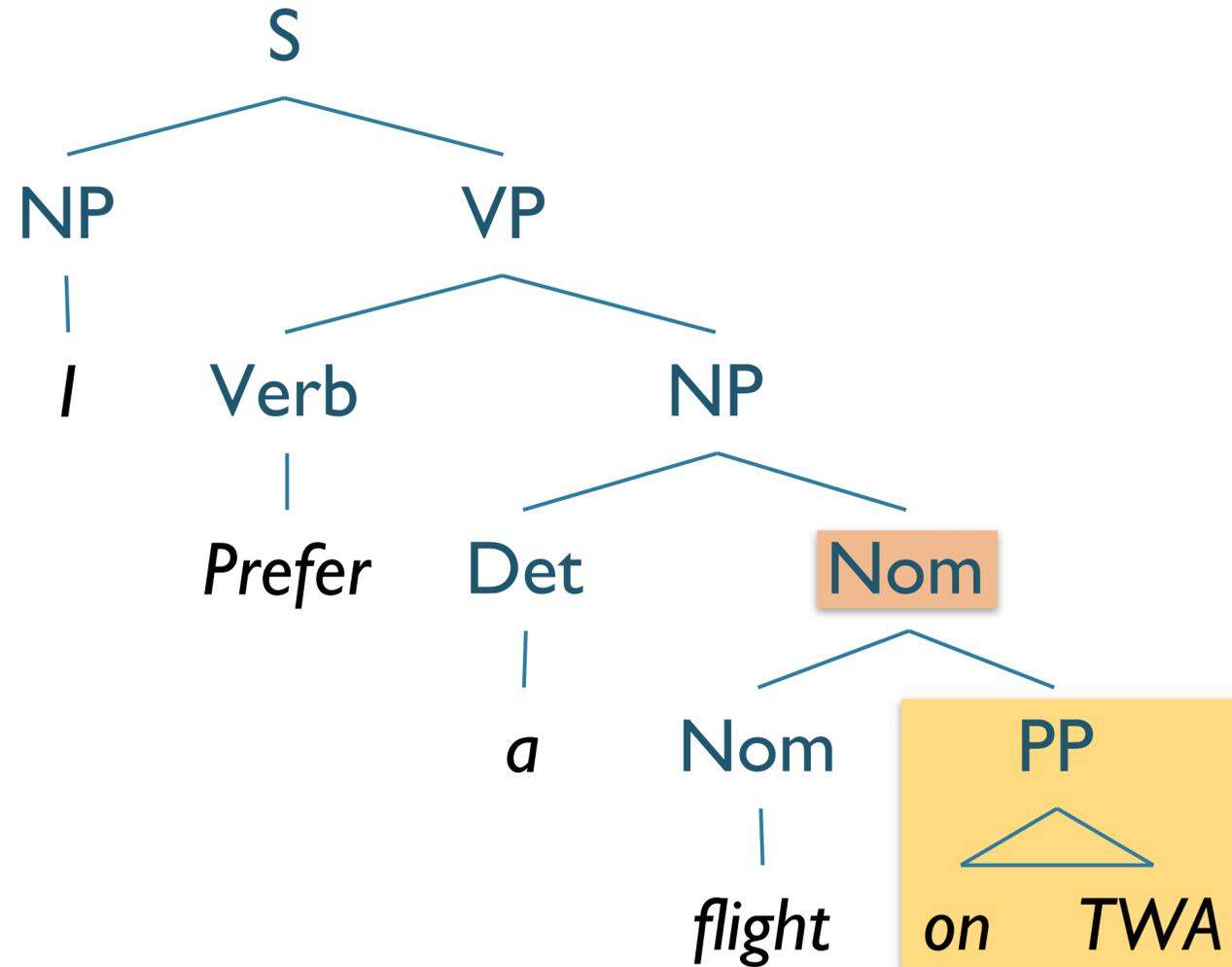
```

bp_2 = BackPointer()
bp_2.l_child = [X2, (1, 4)]
bp_2.r_child = [PP, (4, 6)]

```



# Resulting Parses



# CKY Discussion

Running time:

$O(n^3)$  where  $n$  is the length of the input string

Inner loop grows as square of # of non-terminals

Expressiveness:

As implemented, requires CNF

Weak equivalence to original grammar

Doesn't capture full original structure

Back-conversion?

Can do binarization, terminal conversion

Unit productions requires change in CKY

# Unit Testing

# Unit Testing

- Strategy of testing individual pieces of code in isolation
- Helps ensure:
  - Basic functionality in isolation
  - Complex functionality when individual components are combined
- In many industry jobs, you can't commit code without unit tests!

# Unit Testing in Python

- Many good tutorials on the web [[here's one](#)]
- In a nutshell:

```
from unittest import TestCase

class longTests(TestCase):
    def test_three(self):
        length_3_rule = parse_productions('A -> B C D')
        target_rules = parse_productions('''A -> B _X0_
                                         _X0_ -> C D''')
        self.assertEqual(set(target_rules),
                         set(fix_long_rules(length_3_rule)))
```

# Unit Testing in Python

- “nose” is a test running framework that will detect all `test_*` method functions

```
python3 -m nose hw2.py
```

# Unit Testing in Python

- “nose” is a test running framework that will detect all `test_*` method functions

```
python3 -m nose hw2.py
```

```
AssertionError: Items in the first set but not the second:
```

```
A -> B _X0_
```

```
_X0_ -> C D
```

```
Items in the second set but not the first:
```

```
A -> B C
```

```
-----  
Ran 12 tests in 0.040s
```

```
FAILED (failures=1)
```

# Unit Testing

- Good practice:
  - Save input that crashes your program for a unit test
- Other popular unit testing frameworks for python:
  - pytest: <https://docs.pytest.org/en/6.2.x/>